STDN NO. 101.1

N75-78163

STDN
USER'S GUIDE
BASELINE DOCUMENT

REVISION 2

MAY 1974

(NASA-TM-X-72932) STDN USER'S GUIDE BASELINE DOCUMENT (NASA) 124 p

N75-78163

Unclas

00/98 03939

GSFC

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

STDN
USER'S GUIDE
BASELINE DOCUMENT

May 1974

Revision 2

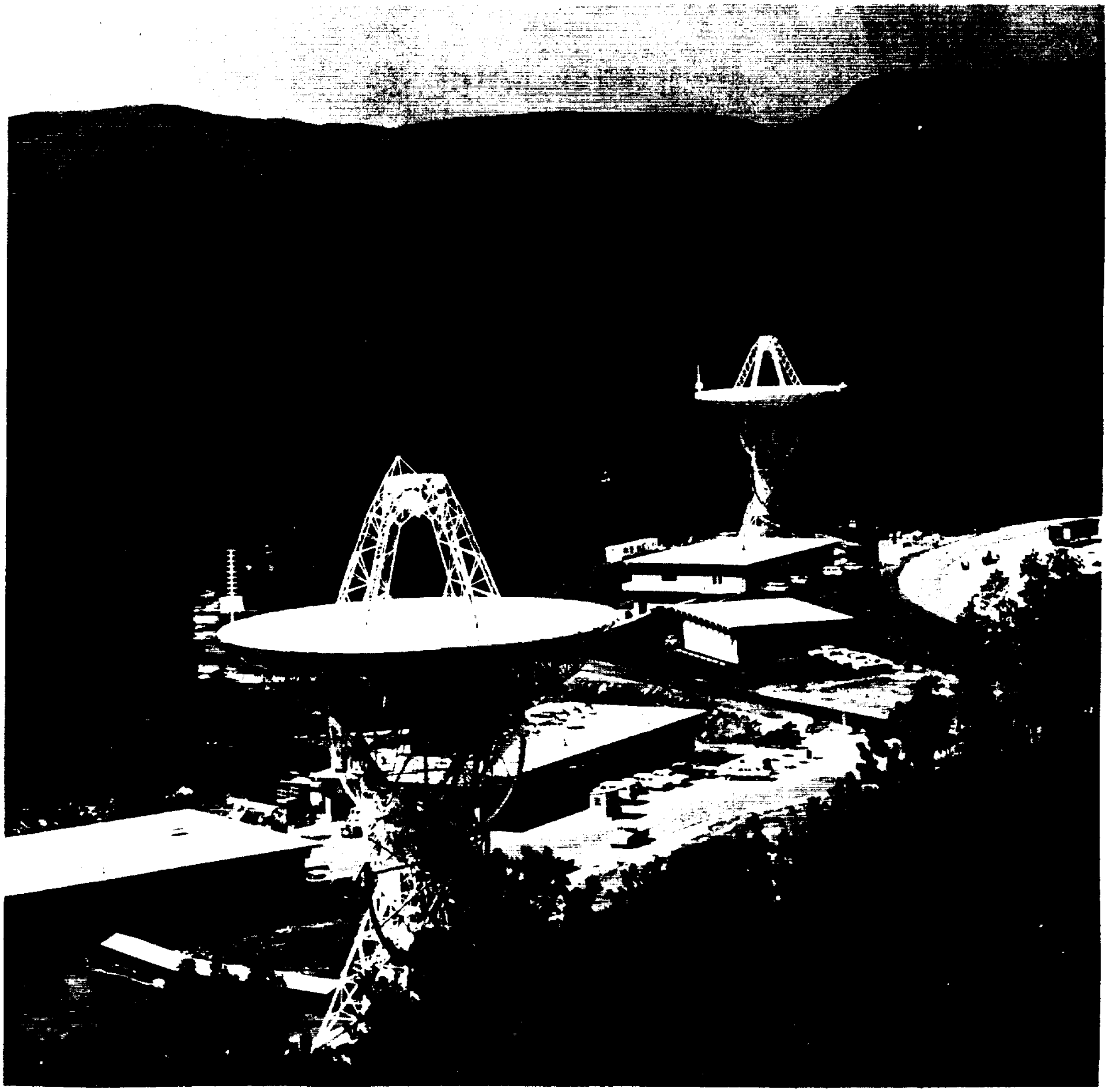
Prepared by: J. N. Scott
Requirements and Plans Office

Approved by: R. R. Nuttall, Chief
Requirements and Plans Office
Code 801

This document supersedes the previous issue of the Spaceflight Tracking and Data Network User's Guide, dated April 1972. Destroy all previously issued copies.

GODDARD SPACE FLIGHT CENTER

Greenbelt, Maryland



Frontispiece. Rosman 26-meter (85-ft) Multiband Telemetry Antennas

Preface

The STDN User's Guide is intended primarily for use by individuals who are, or who are contemplating becoming, users of the network. It provides an overall summary description of network resources and capabilities and it also serves as a network baseline document. This document will be revised and reissued periodically as required by changes in network structure and may, therefore, be of assistance as a source of current network status information to other than network users. The contents of this document are presented in three sections: section 1 gives an overall summary and network description, section 2 describes the procedures for obtaining use of the Spaceflight Tracking and Data Network, and section 3 provides a description of network systems and capabilities.

The information presented in this document does not obligate the National Aeronautics and Space Administration in any way. The data presented, especially that concerning projected Spaceflight Tracking and Data Network capabilities, are subject to change through budgetary constraints or management decisions.

Comments and/or questions concerning this document and its contents should be directed to:

Requirements and Plans Office
Code 801
Goddard Space Flight Center
Greenbelt, Maryland 20771

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (cont)

TABLES

Section 1. The Spaceflight Tracking and Data Network

1.1 GENERAL DESCRIPTION

The Spaceflight Tracking and Data Network (STDN) is a world-wide complex of stations used to provide communications with both manned and unmanned spacecraft. Station locations are shown on the world map in figure 1-1 and are tabulated in table 1-1. The northernmost station is Fairbanks, Alaska (65-deg north latitude) and the southernmost station is Orroral Valley, Australia (35-deg south latitude). In addition to fixed land-based stations, the network includes portable land-based stations, a ship, and several specially equipped aircraft.

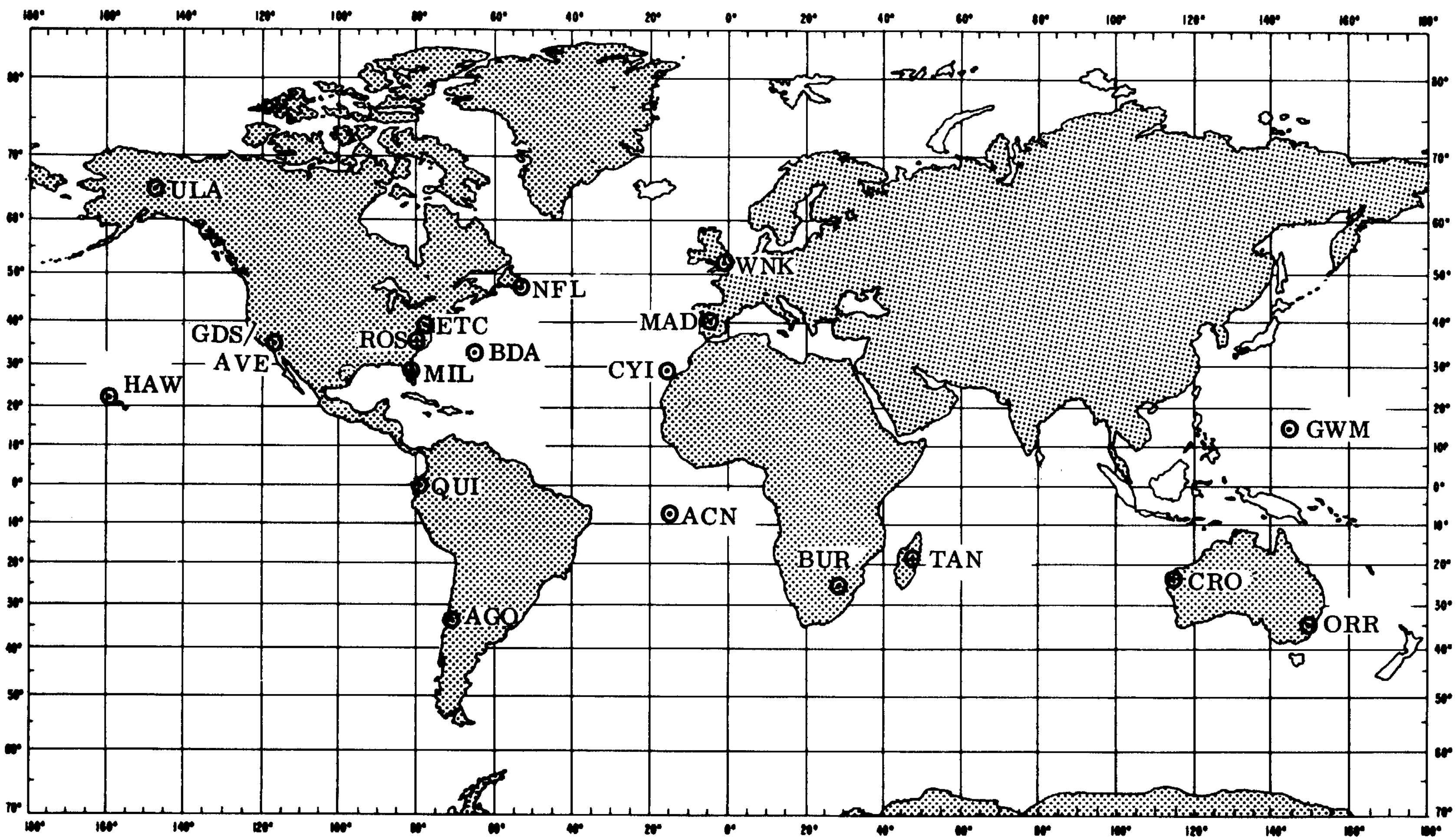
The network is operated primarily in direct support of NASA's earth-orbiting scientific and applications satellits and manned space flight programs, but also may be used in support of other NASA programs (e.g., assistance to the Jet Propulsion Laboratory [JPL] Deep Space Network [DSN] in support of deep space launches, and in launch support of the Wallops Center). The network may also be used in support of the programs of other agencies and organizations, and in the support of programs of other nations.

Real-time operational control and scheduling of the network is provided by the Network Operations Control Center (NOCC) located at the Goddard Space Flight Center (GSFC), Greenbelt, Maryland. A central computing facility, also at GSFC, provides the computational capability required for network operation and analysis.

Spacecraft operations are conducted through the STDN stations from Project Operation Control Centers (POCC's) or, for manned flight, from the mission control center at the Lyndon B. Johnson Space Center (JSC) in Houston, Texas. POCC's (normally located at GSFC) provide centralized operations and control support for each project-unique spacecraft unmanned mission, from inception through the lifetime of the spacecraft.

Telemetry data received by the STDN stations may be recorded on magnetic tape and mailed or transmitted from the station using high-speed data transmission techniques. Manned flight telemetry data is normally sent to the JSC. Data from unmanned spacecraft is typically received and processed at GSFC for delivery to the appropriate user. Spacecraft position data generated by the station tracking instruments is handled in a similar manner. Spacecraft command data may be transmitted in real time from a control center through individual STDN stations, or alternatively, command messages may be stored on station for later transmission to the spacecraft.

Data transmission to and from the STDN is accomplished by the NASA Communications Network (NASCOM), a global network established by NASA to provide operational ground communications for support of all NASA spaceflight projects and other cooperating programs. In addition to communications between the STDN stations and GSFC and JSC operations and data processing facilities, NASCOM provides communications to the stations of the DSN operated by JPL in support of deep space missions, and to the JPL spaceflight operations center, the Marshall Space Flight Center (MSFC) and other center project activities. NASCOM also provides communications to other remote locations and facilities used by the projects, e.g., launch facilities, spacecraft contractors and spacecraft checkout facilities, various test and development sites and contractors, and principal experimenters and investigators.



Note

1. Three letter station designators are defined in table 1-1.
2. A station at Corpus Christi, Texas, has recently been closed.
3. AVE Applications Technology Satellite (ATS) support station.
4. BUR Scheduled to be closed late in 1975.
5. CRO Scheduled to be closed late in 1974.
6. NFL Temporary station to be used in support of the Apollo-Soyuz Test Project.

Figure 1-1. STDN Station Locations

Table 1-1. Geodetic Coordinates of STDN Station Tracking Systems[1] (Referenced to Fisher '60' Ellipsoid, Semimajor Axis = 6378166 and 1/flattening = 298.3)

Station	System	Latitude[2]	Longitude (E)	Height above ellipsoid (meters)
Ascension Island (ACN)	9m(30-ft)USB	-7°57'17.37"	345°40'22.57"	528
Santiago, Chile (AGO)	9m(30-ft)USB [4] VHF GRARR Interferometer	-33°09'03.58" -33°09'06.06" -33°08'58.10"	289°20'01.08" 289°20'01.07" 289°19'54.20"	706 706 694
Bermuda (BDA)	9 m(30-ft)USB FPQ-6 Radar	32°21'05.00" 32°20'53.05"	295°20'31.94" 295°20'47.90"	-33 -35
Johannesburg, Republic of South Africa [3] (BUR)	Interferometer	-25°53'00.75"	27°42'26.99"	1519
Carnarvon, Australia[3] (CRO)	9m(30-ft)USB VHF-GRARR	-24°54'23.52" -24°54'15.02"	113°43'32.06" 113°42'59.84"	3 -4
Grand Canary Island (CYI)	9m(30-ft)USB	27°45'51.61"	344°21'57.89"	167
Engineering Training Center, Maryland (ETC)	9m(30-ft)USB 9m(30-ft)USB (ERTS) Interferometer	38°59'54.84" 38°59'54.08" 38°59'57.25"	283°09'26.23" 283°09'29.21" 283°09'38.71"	-1 4 -5
Goldstone, California (GDS)	26m(85-ft)USB 9 m(30-ft)USB (ERTS)	35°20'29.66" 35°20'29.64"	243°07'35.06" 243°07'37.45"	919 913
Guam (GWM)	9m(30-ft)USB	13°18'38.25"	144°44'12.53"	116
Hawaii (HAW)	9m(30-ft)USB FPS-16 Radar	22°07'34.46" 22°07'24.37"	200°20'05.43" 200°20'04.02"	1139 1143
Madrid, Spain (MAD)	26m(85-ft)USB	40°27'19.67"	355°49'53.59"	808
Merritt Island, Florida (MIL)	9m(30-ft)USB No. 1 9m(30-ft)USB No. 2	28°30'29.79" 28°30'27.91"	279°18'23.85" 279°18'23.85"	-55 -55
Orroral Valley, Australia (ORR)	Interferometer	-35°37'32.19"	148°57'15.15"	926
Quito, Ecuador (QUI)	Interferometer	-00°37'22.04"	281°25'16.10"	3546
Rosman, North Carolina (ROS)	4.3m(14-ft)USB [4] VHF GRARR	35°11'45.99" 35°11'42.02"	277°07'26.96" 277°07'26.97"	810 810
Tananarive, Malagasy Republic (TAN)	4.3m(14-ft)USB[4] VHF GRARR Interferometer FPS-16 Radar	-19°01'13.87" -19°01'16.34" -19°00'31.66" -19°00'05.52"	47°18'11.87" 47°18'11.83" 47°17'59.75" 47°18'53.46"	1368 1368 1347 1307
Fairbanks, Alaska (ULA)	9m(30-ft)USB[4] VHF GRARR Interferometer	64°58'19.20" 64°58'17.50" 64°58'36.91"	212°29'13.39" 212°29'19.12" 212°28'31.89"	339 339 282
Winkfield, England (WNK)	Interferometer	51°26'46.12"	359°18'09.13"	87

[1]System locations are subject to minor changes as refinements in positional accuracies are made.

[2]A minus sign (-) indicates south latitude.

[3]Station scheduled to be closed. See note in figure 1-1.

[4]The 4.3-m systems at ROS and TAN and the 9-m system at AGO and ULA were formerly S-band GRARR antennas.

1.2 NETWORK STATIONS AND CAPABILITIES

1.2.1 GENERAL

The approximate locations of stations which make up the STDN are shown on the world map (see figure 1-1). A more precise tabulation of locations is given in table 1-1. Table 1-2 provides data regarding the major capabilities and characteristics of the network systems and the locations of these systems. Also indicated are some of the currently planned changes to the network with which potential users should be aware. The characteristics and capabilities of individual network systems are discussed in detail in section 3 of this document; however, an overview of total network capability can be obtained from table 1-2. The four columns headed telemetry, command, tracking, and A-G voice represent the major functions of the network while the remaining two columns, communications and computers, are included to indicate major capability used in support of these prime functions. A view of a typical STDN station is shown in figure 1-2.

1.2.2 TELEMETRY

Telemetry provides the means by which spacecraft data is relayed to earth. It includes data concerning astronaut performance, spacecraft performance, and experiments. The major antennas and frequencies used to receive telemetry data are indicated in the telemetry columns of table 1-2. The 26-meter (ORR, ROS, and ULA) and 12-meter (AGO, BUR, ETC, QUI, TAN, and ULA) diameter telemetry antennas have multiple frequency band capabilities and are capable of receive-only operation. The usable bands are 2200 to 2300 MHz, 1690 to 1710 MHz, 400 to 402 MHz, and 136 to 138 MHz. (The 1690- to 1710-MHz band is usable only at Rosman, North Carolina, and Fairbanks, Alaska. Instrumentation has been provided for these bands at only these locations.) The two 9-meter telemetry antennas (BDA and VAN) are receive only in the 2200- to 2300-MHz and 225- to 260-MHz bands and the 4.3-meter antenna (WNK) receives in the 400- to 402-MHz band. The 4.3-meter, 9-meter, and 26-meter Unified S-band (USB) antennas have both transmit and receive capability but receive only the 2200- to 2300-MHz band. (The terminology USB derived from the fact that multiple support functions may be accomplished by this single "unified" system.) The SATAN, AGAVE, and TELTRAC antennas are single frequency band array antennas. The SATAN receives in the 136- to 138-MHz band and the latter two in the 225- to 260-MHz band. A few additional type antennas exist in the network, including special purpose antennas and reduced capability obsolete systems. Examples are a 136- to 138-MHz receive-only "billboard" antenna on the USNS Vanguard (VAN), some older Yagi's at several stations, and special purpose antennas for the Application Technology Satellite (ATS) program at Rosman and Mojave (AVE). (Mojave is a special purpose ATS support station near Goldstone, California and is not listed in table 1-2.)

1.2.3 COMMAND

A variety of command systems and frequencies is available for transmission of messages to the spacecraft. The USB system transmits a carrier frequency from 2090 to 2120 MHz, although this uplink capability is being expanded to 2025 to 2120 MHz. The 450-MHz capability has been and is being used primarily for manned flight support. [It is planned to discontinue this service after the joint US-USSR Apollo-Soyuz Test Project (ASTP) manned mission is completed in July 1975.] The 147- to 155-MHz frequency is widely used for unmanned satellite support; however, discontinuance of its use is also planned (refer to para 1.3).

Table 1-2. Network Systems Capability

Network Function / Station	Telemetry: Antennas												Telemetry: Receive Freq.					Command			Tracking				Communications				Computers			
	2-Yagi [4]	9-Yagi [4]	26m (85') TLM	12m (40') TLM	9m (30') TLM	4.3m (14') TLM [4]	26m (85') USB	9m (30') USB	4.3m (14') USP	SATAN [4]	AGAVE [4]	TELTRAC [4]	2200-2300 MHz	1690-1710 MHz [4]	400-402 MHz [4]	225-260 MHz [4]	136-138 MHz [4]	S-band (USB)	450 MHz [4]	150 MHz [4]	USB	GRARR (VHF) [4]	C-band	Interferometer [4]	VHF A-G Voice [4]	USB A-G Voice	High-speed Data	Wideband Data	T&C (642B)	CDP (1230)	1218	H-316R (SCE)
Acension Island (ACN)								O		O		O	O			O	O	O	O	O	O				O	O	O		O		O	O
Santiago (AGO)				O				O		O			O		O		O	O		O	O	O		O		X	O		O		O	O
Bermuda (BDA)	O				O			O			O		O			O	O	O	O		O		O		O	O	O		O		O	O
Johannesburg (BUR) [1]				O						O			O		O		O			O				O			O					O
Carnarvon (CRO) [2]								O					O				O	O			O	O				O	O		O		O	O
Grand Canary Island (CYI)		O						O			O	O	O			O	O	O	O		O				O	O	O		O		O	O
Engineering Training Center (ETC)		O		O				O		O	O		O		O	O	O	O		O	O			O	O	O	O		O		O	O
Goldstone (GDS)							O	O				O	O			O		O	O		O				O	O	O		O		O	O
Guam (GWM)								O		X		O	O			O	X	O	O	X	O				O	O	O		O		O	O
Hawaii (HAW)								O		X	O	O	O			O	X	O	O	X	O		O		O	O	O		O		O	O
Madrid (MAD)							O	X				O	O		O	O		O	O		O				O	O	O	O	O		O	O
Merritt Island (MIL)								O		O		O	O			O	O		O	O	O				O	O	O		O		O	O
Ororral Valley (ORR)			O					X		O			O		O		O	X		O	X	X		O	X	X	O	O	X		O	O
Quito (QUI)				O					X	O			O		O		O	X		O	X			O		X	O		X		O	O
Rosman (ROS)			O					X	O	O			O	O	O		O	O		O	O	O				X	O	O	X		O	O
Tananarive (TAN)				O					O	O			O		O		O	O		O	O	O	O	O		O	O		O		O	O
Corpus Christi (TEX) [3]																																
Fairbanks (ULA)			O	O				X		O			O	O	O		O	X		O	X	O		O			O	O	O		O	O
Vanguard (VAN)					O			O					O			O	O	O	O	O	O		O		O	O	O		O	O	O	O
Winkfield (WNK)						O				O					O		O			O				O			O		X			O

Legend

O Existing.

X Currently being implemented, procured, or planned.

Note

1. To be closed in late 1975.
2. To be closed in late 1974.
3. This station has recently been closed.
4. Use of these frequencies/systems is being phased out (refer to para 1.3).

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

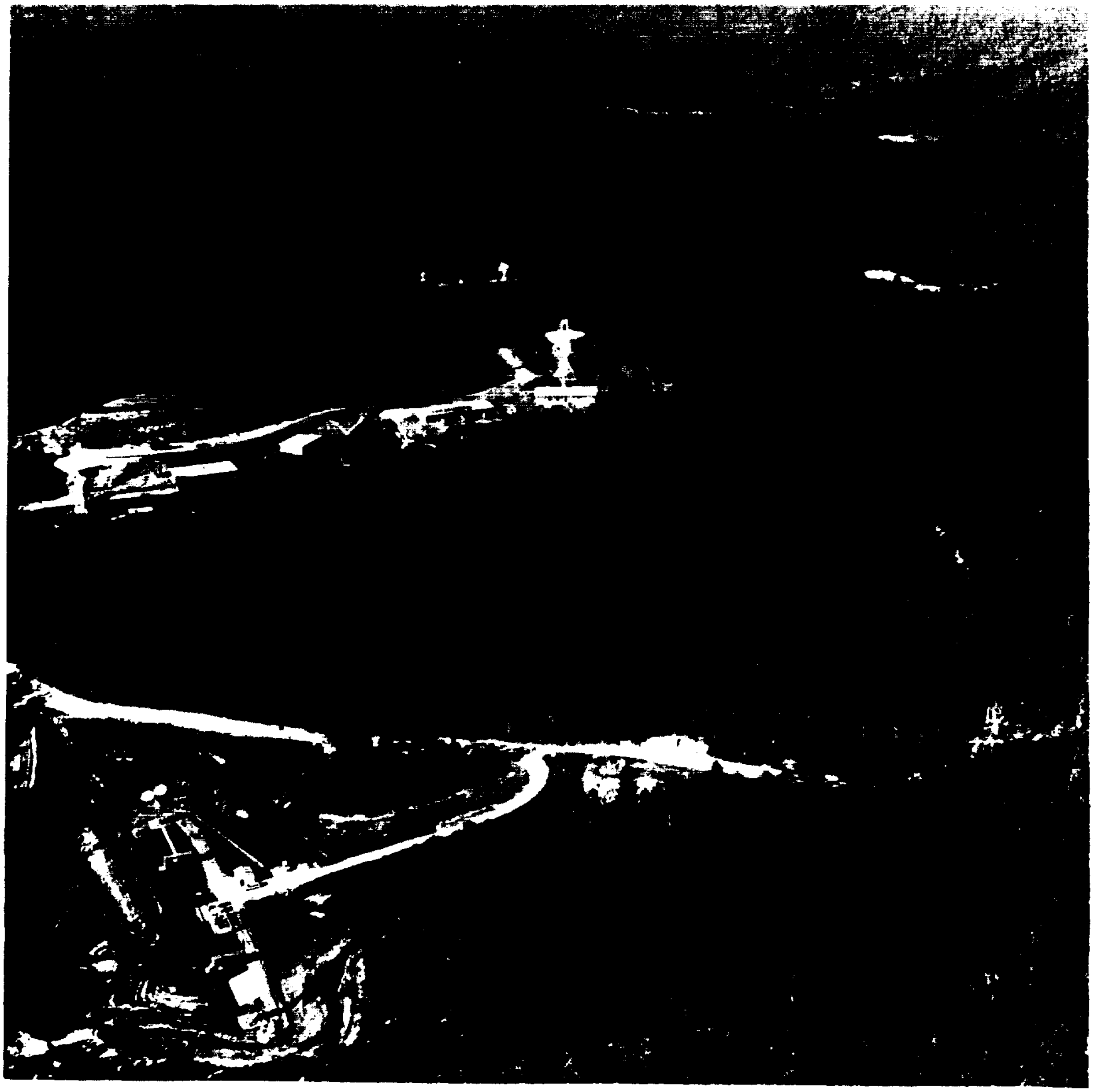


Figure 1-2. Typical STDN Station

1.2.4 TRACKING

The spacecraft tracking function employs several systems including conventional C-band pulse radar, an interferometer system operating at 136 MHz, the VHF Goddard Range and Range Rate system (GRARR) which operates at 150-MHz uplink and 136-MHz downlink, and the USB system. It should be noted the USB classification includes the formerly designated S-band GRARR system which is being modified to operate at USB frequencies and perform the telemetry, command, and voice functions.

1.2.5 AIR-TO-GROUND VOICE

Air-to-ground (A-G) voice is used for manned flight support using either the USB system or a VHF voice system. Use of the VHF voice system will be discontinued after the ASTP mission in July 1975.

1.2.6 DATA TRANSMISSION

The communications column in table 1-2 indicates that all stations currently have high-speed data capability. This service provided by NASCOM permits transmission of data between the STDN stations and control centers using voice bandwidth circuits at a rate of 7.2 kb/sec for each circuit. Greater bandwidth circuits are available from some of the stations as indicated in the wideband data column.

Computers are used on station for processing spacecraft-associated data in addition to local equipment test and control functions. Data processing capabilities range from simple format filling to sophisticated data compression operations.

1.2.7 PORTABLE FACILITIES

Most STDN support stations are at fixed land sites; however, portable facilities are also used. The Vanguard, shown in figure 1-3, was designed primarily for Apollo orbit-insertion support but is used also for unmanned flight support. As indicated in table 1-2, the Vanguard is extensively instrumented. Vanguard's capabilities are enhanced by a communications satellite terminal which permits reliable relay of data via Intelsat satellites. A precision navigation system provides a continuous measure of the ship's position and other navigational data required to permit accurate spacecraft tracking. This capability may also be used in conjunction with oceanographic or other activities such as depth soundings or weather observations. Major antenna systems on the Vanguard (see figure 1-3) can be identified (bow-to-stern) as follows: VHF voice/UHF command antenna; SATCOM 9-meter antenna; C-band radar 4.9-meter antenna; USB 9-meter antenna; telemetry 9-meter antenna (4-1); telemetry antenna (4-2) (below forward HF communications log periodic antenna).

A fleet of aircraft is operated for NASA by the U.S. Air Force. Originally eight planes were built and outfitted for joint NASA/DOD use. These aircraft were initially designated Apollo Range Instrumentation Aircraft but are now known as Advanced Range Instrumented Aircraft (ARIA). They have been used by NASA primarily for Apollo and Skylab project support. They can receive multiple S-band and VHF links, and can uplink voice but not ranging or command data. The aircraft are pictured in figure 1-4.

Portable land stations have been used in support of both manned and unmanned space programs. These facilities in the past have generally been configured to fit specific requirements and, therefore, are not readily available as general support facilities. They include a portable facility currently located near Goldstone, California (Mojave), which will be used in support of the ATS-F unmanned spacecraft, and a facility in St. John's, Newfoundland, which will support the ASTP manned launch.

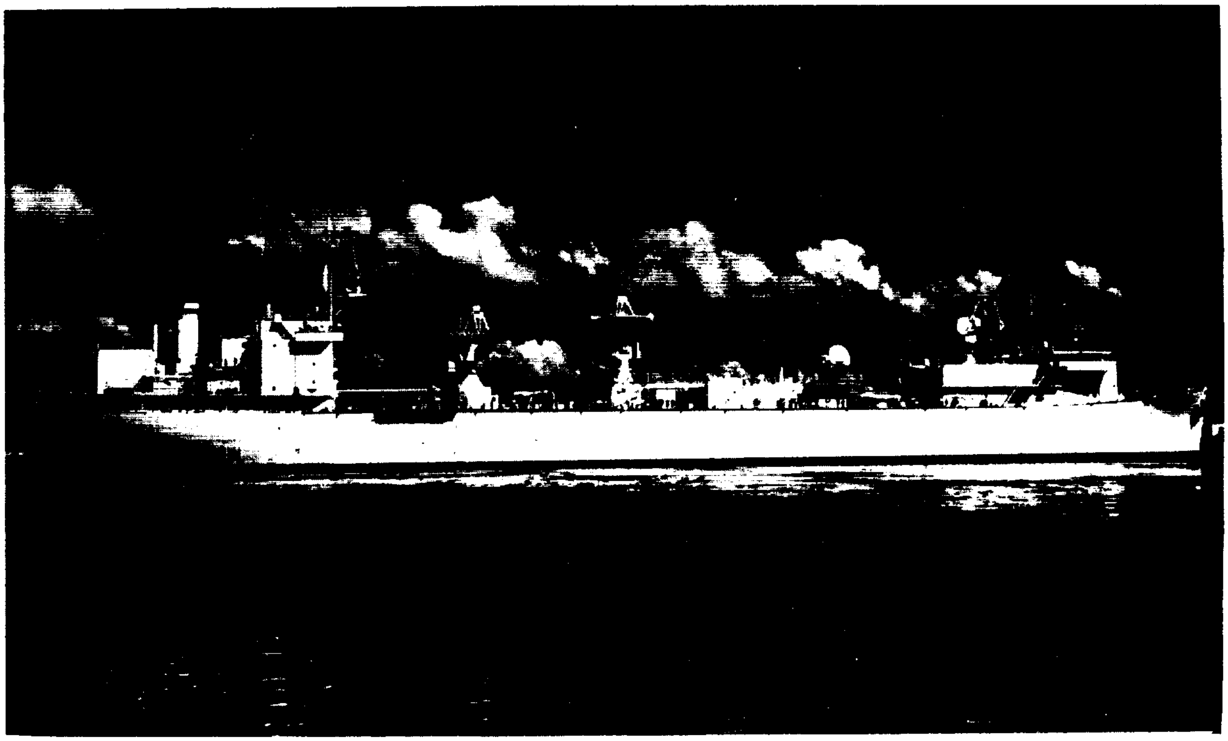


Figure 1-3. USNS Vanguard

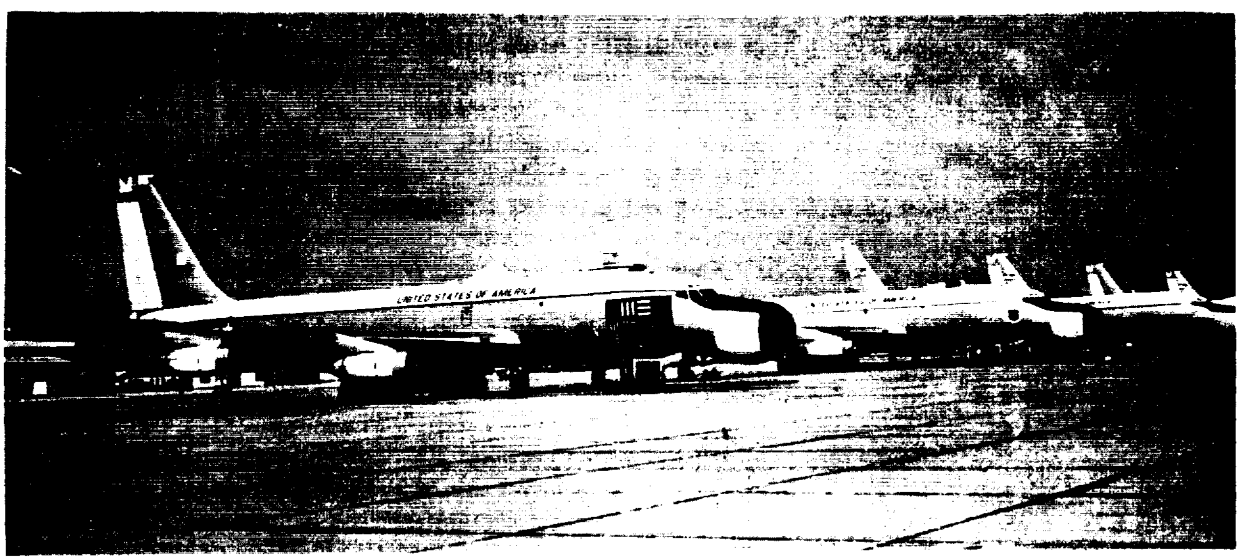


Figure 1-4. Advanced Range Instrumented Aircraft

1.3 NETWORK FUTURE PLANS

1.3.1 GENERAL

The STDN is now composed of the facilities of two previously independent networks: The Space Tracking and Data Acquisition Network (STADAN) and the Manned Space Flight Network (MSFN). The STADAN was used primarily for unmanned spacecraft support while the MSFN was designed and equipped to support the U.S. manned flight programs. Generally, the nature of the support requirements and frequency usage prior to consolidation of the networks prohibited significant cross support between the networks. For example, manned flight telemetry was supported in the 225- to 260-MHz and 2270- to 2300-MHz frequency bands while unmanned programs utilized telemetry frequencies at 136, 400, and 1700 MHz. Also, individual network station locations were optimized for the type of support to be provided. The networks were formally combined in May 1971.

The consolidation of the two networks has yielded economies in operation and equipment utilization and increased operational flexibility and spacecraft coverage capabilities of the network. Equipment utilization study results have been and are being used to optimally locate existing network equipment in order to minimize the number of required stations without degrading coverage capability. The former STADAN station at Fort Myers, Florida, has been closed; a former MSFN station at Honeysuckle Creek, Australia, has been transferred to the JPL for use in support of deep space missions. The station at Corpus Christi, Texas, has recently closed. Carnarvon, Australia, and Johannesburg, South Africa, are scheduled to be closed in 1974 and 1975, respectively. The equipment from these stations has been or will be transferred to other stations to provide standardized support services from the optimally located stations. Table 1-2 indicates the major antenna systems and support services which are planned for the various stations.

The trend toward higher spacecraft data transmission rates has resulted in increased use of the 2200- to 2300-MHz frequency band and the correspondingly greater available bandwidths at these frequencies, along with a projected decrease in use of the lower VHF frequencies. Accordingly, plans call for eventual phasing out use of all VHF frequencies and increasing somewhat the network capabilities at S-band frequencies. These improvements include a widening of the USB uplink transmission frequency band from the present 2090- to 2120-MHz capability to 2025 to 2120 MHz. This will permit coherent operation throughout the 2200- to 2300-MHz receive band. (Coherent operation is required for Doppler ranging as described in para 3.2.) Other improvements include the implementation of additional multifunction receivers (refer to para 3.6.4.3) and the implementation of a tone ranging system to replace the Pseudorandom Noise (PRN) system currently used with the USB system (refer to para 3.2.2.3).

A standardized station data handling system will be provided by the planned Digital Data Processing System (DDPS). Basically, this concept provides for reconfiguration and redistribution of existing Univac 642B computers throughout the network to provide a general purpose data processing capability at each station. These computers will be complemented by additional smaller computers and memory units to provide increased command and telemetry data processing capability and flexibility. The DDPS concept has replaced the previous Station Data Acquisition and Control (STADAC) system concept.

Planned phaseout of the use of VHF and other frequencies is consistent with the planned introduction of a satellite relay system. The Tracking and Data Relay Satellite System (TDRSS) will use S- and Ku-band frequencies. Spacecraft equipped to operate with this system will not be compatible with currently used VHF systems.

Accordingly, it is desired that spacecraft launched in 1978 or after do not use 136-MHz telemetry or 148-MHz command systems and that use of the 225-MHz telemetry and 450-MHz command systems not be planned following the ASTP mission. It is also planned to discontinue use of the 400- to 402-MHz and 1750- to 1850-MHz telemetry receive bands by January 1, 1976, except that Rosman and Fairbanks will continue to support in the 1750- to 1850-MHz band as long as required.

The TDRSS is scheduled to become operational in 1979. This system will be integrated into the STDN, and its introduction will greatly increase total available earth-to-spacecraft communications (coverage) capability; also, a further reduction in the number of STDN stations will be practicable. The stations remaining will be selectively equipped with Ku-band capability to provide compatibility with TDRSS and partial backup to the TDRS user spacecraft. (Current plans indicate that the following STDN stations will be retained in the TDRS time frame: Bermuda, Goldstone, Madrid, Merritt Island, Orroral, Rosman, Tananarive, and Fairbanks.)

1.3.2 TRACKING AND DATA RELAY SATELLITE SYSTEM

A brief description of the TDRSS salient characteristics and capabilities is given in para 1.3.2.1 through 1.3.2.6. It should be emphasized that, while the following information accurately reflects current planning, it is subject to change, and potential users of the TDRSS should keep abreast of current developments. Current plans are that the system will be provided and operated through a lease arrangement.

1.3.2.1 General Description. The TDRSS will consist of two operational satellites in geosynchronous orbits spaced approximately 130 deg apart, at 41 and 171 deg west longitude. Inclination will be between 2 and 7 deg. A TDRS ground terminal located within the continental U.S. (presently planned for White Sands, New Mexico) will operate with the satellites to provide a telecommunications service for transferring tracking, telemetry, command, voice, and image data between the ground and low earth-orbiting user spacecraft. This service will provide a minimum coverage of 85 percent of the user spacecraft orbit for orbits below 5000 kilometers. For these orbits, the TDRSS will be the prime network support system. For higher altitude orbits, the reduced number of remote STDN stations will provide the primary support service.

To ensure operational reliability, a spare satellite will be placed in synchronous orbit midway between the two operational satellites, and another satellite will be maintained on the ground for rapid replacement launch if necessary. The ground terminal will maintain a backup antenna system in addition to the two operational antennas (one for each operational satellite). Ground station antennas will be 18.3-meter parabolic antennas spaced several miles apart.

Each satellite will have two dual-feed S-band/Ku-band 3.8-meter parabolic antennas plus a multi-element S-band array antenna. These antennas will be used primarily to relay communicataions to and from user spacecraft. A fourth antenna, a 1.8-meter parabolic Ku-band antenna, will provide the prime link for relay of transmissions to and from the ground terminal. (Additional spherical coverage S-band antennas will be provided for use during launch and for test and housekeeping functions. These antennas and the associated ground link provide no user-oriented services.)

The 3.8-meter antennas and associated systems will provide a single access service to user spacecraft. The array antenna will support multiple access users. These terms are detailed in para 1.3.2.2 and 1.3.2.3.

1.3.2.2 Single Access Service. Both of the 3.8-meter antennas on each TDRS can simultaneously support two spacecraft users, one each at S-band and Ku-band frequency, if the S-band and Ku-band users are within the antenna beamwidth. This is termed single access service because only one user at a time can use a given antenna/feed combination, although, clearly, more than one user at a time can be supported with this service.

The nature and capacity of the S-band/Ku-band link for each TDRS are as follows (margin calculations and bit rate capabilities are provided in appendix A):

a. S-band Single Access Service. This service provides for relaying up to 10-MHz RF bandwidth from either one or two S-band users at a time, using a discrete frequency in the 2200- to 2300-MHz frequency band. This is the user-to-TDRS or return link. Nominal maximum bit rate capacity is expected to be 5 Mb/sec. The TDRS-to-user, or forward link, provides for transmission to two users simultaneously from each TDRS on a discrete carrier in the 2025- to 2120-MHz band.

b. Ku-band Single Access Service. This service provides for simultaneously relaying up to an 88-MHz RF band from each of two users (return link). Alternatively, if only a single user is being supported, a total of 225 MHz of return link RF bandwidth is available. The constraint to a single user arises because 225 MHz is the total available bandwidth being allocated in the Ku-band downlink. This band extends from 14.896 to 15.121 GHz. Forward link transmissions will be in the 13.75- to 13.8-GHz range with data rates up to 30 Mb/sec feasible. Return link capacity will be as high as 300 Mb/sec using quadriphase (QPSK) modulation and the 225 MHz of available bandwidth.

1.3.2.3 Multiple Access Service. The multiple access service uses the multi-element S-band array antenna and associated systems, and will simultaneously support at least 20 user spacecraft. The array antenna system is called Adaptive Ground Implemented Phased Array (AGIPA).

a. Multiple Access Forward Link. For the forward link (TDRS to user) a single element (26-deg beamwidth) of the AGIPA will be used to transmit command data to the 20 users. Command data will be transmitted to the user on a spread spectrum modulated signal centered at 2106.4 or 2092.6 MHz (frequency coordination currently in process will determine which of these frequencies will be selected). This will be achieved by modulo-2 adding the command data bit stream to a 1.5-Mb/sec PRN sequence code, and modulating the carrier with this composite bit stream. The command data for each user spacecraft will be time-division-multiplexed at the TDRSS ground terminal and will be time shared by the users. Each user will require a correlation receiver to remove the PRN code and recover the command data, which will be identified by a unique address for each user. Command data rates for all multiple access users are expected to be fixed at approximately 100 to 200 bits/sec.

b. Multiple Access Return Link. For receiving, the AGIPA antenna will have 30 antenna elements. The ground equipment portion of AGIPA will perform the necessary signal processing, combining the signals from each element in amplitude and phase, to form 20 simultaneous independent beams. The individual beams will be steered automatically by a ground computer programmed with an algorithm designed to optimize the output Signal-to-noise Plus Interference (S:N&I) ratio for each user. In this computation, other user spacecraft that fall within the antenna beam of a desired user represent interference sources. Therefore, up to 20 user spacecraft may simultaneously transmit telemetry data, each using a unique TDRS antenna beam.

Each user will generate a unique 1.5-Mb/sec PRN code which has been added (modulo-2) to that user's telemetry bit stream, and the composite signal will be modulated on to a 2287.5-MHz carrier frequency (2272.5 MHz may be selected in lieu of 2287.5 MHz) for transmission to the TDRS. A nominal total return link bit rate of 100 kb/sec is planned but the rate of individual users will be a function of this Effective Isotropic Radiated Power (EIRP) and the number of other simultaneous users. The 2287.5-MHz spread spectrum modulated signal will be relayed, with similar signals from other users, by the TDRS to the ground terminal. Individual user data will be extracted at the ground terminal by a correlation process identifying the specific PRN code of each user. It is apparent that to be compatible with the TDRS multiple access service, each user will have to fly some type of PRN transponder. This will also provide a tracking capability.

1.3.2.4 TDRS Tracking Data. Ranging information for multiple access users can be obtained by synchronizing forward and return link PRN codes at the user spacecraft. This permits a measurement of propagation time and spacecraft range. Doppler information will be obtained by using a reconstructed carrier component of the user spacecraft transmitted signal.

For single access payloads there are no restrictions on the modulation techniques because the TDRSS acts as a "bent pipe" repeater on both the forward and return links. TDRS transmissions to user spacecraft are required, however, to satisfy flux density restrictions imposed by the International Radio Consultive Committee (CCIR). This requirement may be accomplished by PRN technology (as the forward link commanding) or by otherwise spreading the forward link transmitted power over a sufficiently wide bandwidth.

Studies have shown that for orbit maintenance the TDRSS will be capable of tracking a spacecraft to an accuracy equivalent to that of the current STDN.

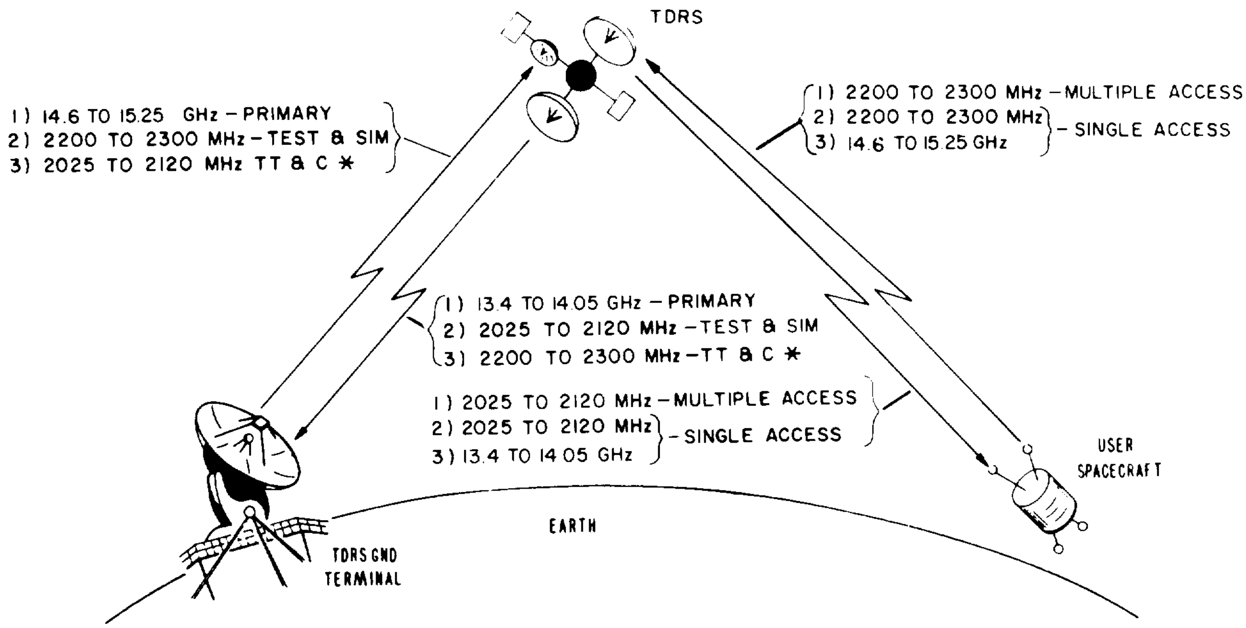
1.3.2.5 TDRS Ground Link. Communications between the relay satellite and the ground terminal will be primarily via a Ku-band link operating with the 1.8-meter antenna on the TDRS. S-band links will be used during the TDRS launch phase and for backup TDRS housekeeping functions during operational phases, and for test and simulation purposes. The satellite acts as a bent pipe relay to the users, i.e., the signals received at the satellite are translated in frequency and retransmitted. Figure 1-5 illustrates frequency usage planned with the TDRSS.

1.3.2.6 Operation. POCC's will communicate with the TDRSS ground terminal through NASCOM lines in a manner similar to communications with other STDN stations. It is planned that the NASCOM lines will be sized as required to handle this data in real time.

Appendix A of this document provides further data and calculations of TDRS/user circuit margins.

1.4 NETWORK MANAGEMENT

The STDN is operated and managed by the Networks Directorate of the Goddard Space Flight Center, Greenbelt, Maryland. Overall management responsibility for tracking and data acquisition matters resides in the Office of Tracking and Data Acquisition, NASA Headquarters, Washington, D.C.



* TRACKING, TELEMETRY AND COMMAND SUBSYSTEM
- PRIMARY DURING LAUNCH PHASE
- BACKUP DURING OPERATIONAL PHASE

Figure 1-5. TDRSS Frequency Plan

Section 2. Procedures for Obtaining STDN Support

2.1 REQUESTING SUPPORT

2.1.1 GENERAL

The STDN is managed and operated by the Networks Directorate of the GSFC under the direction of Office of Tracking and Data Acquisition (OTDA), Code T, NASA Headquarters.

NASA Management Instruction, NMI 8430.1A dated September 12, 1969, prescribes the policies, responsibilities, and procedures for planning, managing, and documenting tracking and data acquisition support for unmanned space flight projects.

In general, NMI 8430.1A states that after a NASA program has been approved by the appropriate program office, the tracking and data acquisition requirements are documented in official requirement documents and submitted to OTDA for review and concurrence. Department of Defense (DOD) programs requesting NASA tracking and data acquisition support are also submitted to OTDA via the DOD Research and Engineering Office (DDR&E). After obtaining OTDA approval, the requirement documents should be sent to:

Code 801
Goddard Space Flight Center
Greenbelt, Maryland 20771
Attn: Chief, Requirements and Plans Office
(Phone No. 301-982-2881)

The Networks Directorate has designated the Requirements and Plans Office as the point of contact for receiving network support requirements. Any request for information related to STDN capabilities or procedures should be forwarded to this office.

2.1.2 SPECIAL COMMUNICATIONS SUPPORT REQUIREMENTS

Requirements involving NASCOM support of JPL/SFOF, JSC, MSFC, and other center project activities that do not involve STDN support need not be sent to the Requirements and Plans Office, as they are handled by other established channels. Generally, requirements for NASCOM support involving projects' use of facilities other than those of the STDN may be included to the extent feasible in the previously mentioned NASA and DOD requirements documents. However, in many cases, these will not be of a nature appropriate or timely for inclusion in such documents. In this case, a requirements letter in duplicate may be addressed directly to:

Code 840
Goddard Space Flight Center
Greenbelt, Maryland 20771
Attn: Chief, NASA Communications Division

Code 840 will direct such requirements into proper channels.

2.1.3 REIMBURSEMENT FOR STDN SUPPORT

2.1.3.1 NASA Projects. NASA project requirements for STDN support of NASA missions is funded through normal budget channels whereby OTDA justifies their budget based on official NASA requirements. Hence, there is no charge to NASA project offices for STDN services.

2.1.3.2 Non-NASA Projects

Note

> Special arrangements may be made with other U.S. Government agencies and other foreign governments on cooperative projects for reimbursements other than these specified.

a. U.S. Government Projects. STDN services are available to other non-NASA U.S. Government projects (including DOD) for the actual additive cost (e.g., special planning, testing, documentation, travel, overtime of station operating personnel) incurred in support of the project. There is no charge for Tracking and Data Acquisition (T&DA) support provided by the STDN equipment operated during the normal scheduled hours of operation of the stations.

b. Non-U.S. Government Projects. STDN services are available to non-U.S. Government projects for the total cost of the support provided to the project.

2.1.4 REQUIREMENTS DOCUMENTS

Officially authorized program requirements are listed in the following documents. Thirty copies of these documents should be sent to the Requirements and Plans Office when STDN support is requested.

a. NASA Requirements Documents. NASA project offices requesting T&DA support must document and publish their requirements in a Support Instrumentation Requirements Document (SIRD). The SIRD is approved by the cognizant NASA Headquarters office: Associate Administrator for Space Science, Advanced Research and Technology, or Applications, then forwarded to the Associate Administrator for Tracking and Data Acquisition for review.

b. DOD Requirements Documents. Support requirements (other than range safety requirements) originated by agencies of the DOD are authorized by the Director of Range Operations and are published in a Program Requirements Document (PRD) and/or an Operations Requirements Extract (ORE). DOD must obtain OTDA approval for each program that the STDN is requested to support. After OTDA approves the DOD request, the PRD and/or ORE are the authorized requirements documents for the program. Ordinarily, in the DOD system, the PRD is preceded by a Program Introduction (PI) document which summarizes the nature of the planned program and the general support requirements.

c. Range Safety Requirements. Range safety requirements for Bermuda will be sent to GSFC via the Goddard Network Support Office at Patrick Air Force Base, Florida, in accordance with the DOD/NASA agreement of October 1964, Joint Use Plan of NASA Facilities by the AFETR.

2.1.5 LEAD TIME FOR THE SUBMISSION OF REQUESTS

Many new program requirements are compatible with existing equipment; however, some require new hardware and software which necessitates long lead times for implementation. Also, DOD requests for new program support from stations located in foreign countries must be approved by the responsible foreign government. NASA Headquarters negotiations for obtaining approval for such programs may take one or more years. To ensure that all program support requirements are received in adequate time for response, the following lead times are required:

a. Requests for support not requiring the generation of new software or any hardware modifications should be submitted at least 3 months in advance of the proposed launch or support period.

b. Requests for supplemental support requiring minor modifications should be submitted at least 6 months in advance of the proposed launch or support period.

c. Requests for supplemental support requiring major modifications should be submitted at least 2 years in advance of the proposed launch or support period.

d. Requests for prime project or program support should be submitted at least 3 years in advance of the proposed launch or support period.

In order to provide information for the NASCOM Data System Development Plan for engineering and budget planning, an annual special solicitation for requirements is made to all NASA field centers. Current and long term projections (up to 5 years) of long haul requirements are made via respective NASA Headquarters institutional directors and OTDA.

2.2 STDN RESPONSE TO REQUESTS FOR SUPPORT

2.2.1 GENERAL

Letters and documents requesting STDN support are received by the Requirements and Plans Office. This office performs a general analysis of the requirements and forwards them to the appropriate line organizations of the Networks Directorate for detailed review and evaluation. The Requirements and Plans Office will assist project personnel, as required, in identifying STDN capabilities and commitments.

The Networks Directorate will assign a Network Support Manager (NSM) for each program requesting support from the STDN. The NSM will plan and prepare network support for the project through a Network Support Committee tailored for the specific needs of the project. The NSM will also coordinate the preparation of the NASA Support Plan (NSP) and the Network Operations Support Plan (NOSP) for the Networks Directorate with the assistance of the Network Support Committee.

2.2.2 RESPONSE DOCUMENTS

The Networks Directorate will respond to support requests with a support confirmation message or an NSP plus an NOSP. The support confirmation message is prepared for support requested via letters, teletype messages, etc.; the NSP is prepared in response to an SIRD in accordance with NMI 8430.1A as discussed previously.

The Chief, Requirements and Plans Office, will send a memorandum or teletype message that will confirm or specify the limitations of the support to be committed to the requested program. This message is used primarily to inform project personnel or other requesters of the general support that the network can or cannot provide.

2.2.3 STANDARDS

Support furnished by any Goddard facility, including the STDN, must conform to the Aerospace Data Systems (ADS) Standards. According to GMI 8070.1, which establishes policies and procedures with respect to the Aerospace Data Systems Standards, any project making use of GSFC facilities must either follow the ADS Standards or obtain a waiver from the Data Systems Requirements Committee (DSRC). These standards have proven in practice to provide a common basis for efficient and reliable interchange of data and represent systems and procedures which are currently feasible in the network. The standards encompass most of the range of support functions which can be furnished by the network. Nonstandard support frequenctly places an additional burden on the network and should be avoided. However, when standard systems are incapable of providing required support or, when a proposed new system has potentially great technical value, waiver requests for support which can be provided through the network are likely to be granted by the DSRC.

Section 3. Network Systems Description

3.1 GENERAL

This section provides details for each of the major network systems and their capabilities.

3.2 UNIFIED S-BAND

The Unified S-band (USB) system was designed and implemented at designated stations as the prime communications support system for the Apollo Project. The system derives its name from the fact that multiple spacecraft support functions (tracking, telemetry, command, air/ground voice, and television) can be performed simultaneously using this unified system. S-band refers to the operating frequency band.

The system has recently been used in support of the Skylab Project and, in addition, is being used increasingly as the prime communications support system for unmanned spacecraft. Major unmanned missions currently supported include the Earth Resources Technology Satellite (ERTS) and the Explorer 51 (Atmospheric Explorer-C) missions. Since projections and plans indicate a continuing increase in USB system use, a number of improvements are planned to be completed by 1976 which will considerably enhance system capability and flexibility and also will result in a more nearly standardized system. The planned improvements consist basically of an expansion of the uplink frequency band, replacement of the present receive systems with a Multifunction Receiver (MFR) system, replacement of the present ranging systems with one of greater accuracy, and a new software-controlled Tracking Data Processing (TDP) system. Both current and planned (where appropriate) systems are discussed in the following information. Refer to tables 1-1 and 1-2 for detailed information concerning current and projected USB locations.

3.2.1 USB SYSTEM GENERAL DESCRIPTION

The USB system as deployed at a typical STDN station consists basically of the following:

a. A parabolic dish antenna and its associated feeds and control system.

b. Equipment used primarily for uplinking information to spacecraft, comprised of an exciter and associated modulation equipment, and a power amplifier.

c. Equipment used primarily for receiving downlink transmissions from spacecraft, comprised of antenna-mounted parametric amplifiers, receivers, and demodulation equipment.

d. Range and range rate equipment which operates with the above equipment to determine spacecraft range and radial velocity.

e. Tracking data processing equipment used to process and format tracking information for recording or transmission to central facilities where it is used in trajectory/orbit computations.

This equipment interfaces with other station equipment as required to provide the multiple support functions indicated earlier.

3.2.1.1 System Configurations. Most USB systems utilize either a 9-meter (30-ft) or 26-meter (85-ft) diameter parabolic dish antenna, and, except for the difference in antenna size and transmitter capability, these USB systems are very similar. This statement applies also to the Vanguard 9-meter system, except that the shipboard antenna employs an azimuth-elevation (az-el) mount. Land-based systems use X-Y mounts. For convenience, smaller 4.3-meter (14-ft) antenna systems at Rosman and Tananarive also have been designated as USB systems in this document. These systems were part of the no longer used S-band Goddard Range and Range Rate (GRARR) system; they have been modified to provide support at USB frequencies. (Uplink frequency capability is 2025 to 2120 MHz and the downlink is 2200 to 2300 MHz.) Current plans are that the Tananarive system will be updated to a "standardized" system in 1975 and the Rosman system will eventually be replaced with a 9-meter standardized system. A third 4.3-meter antenna system, not currently in use, will be implemented at Quito in the standardized configuration and also completed in 1975.

The 4.3-meter antenna systems are considerably different from the 9- and 26-meter USB systems even though they perform similar functions and the comments in the remainder of this USB discussion do not, in general, apply to the 4.3-meter systems. One major difference is the use of dual reflectors instead of diplexers (see figure 3-1) to achieve simultaneous transmit and receive capability.

A 9-meter antenna system (formerly used with the GRARR system) at Fairbanks is being converted, and will be among the first to operate in the standard configuration. The scheduled operational date is February 1975.

The former GRARR 9-meter system at Santiago has been modified and is similar to other USB systems except for reduced capability for multiple link support. (It is considered a "single" system; all others are dual.) It will eventually be standardized also.

Several Advanced Range Instrumented Aircraft (ARIA) operated by the U.S. Air Force in support of NASA and Air Force programs have limited USB capability. These KC 135A transports, pictured in figure 1-4, are equipped with a 2.1-meter (7-ft) parabolic antenna housed in the specially configured nose. They are capable of providing S-band A-G voice communication (with a spacecraft) and of receiving S-band telemetry. They have no command or ranging capability. The ARIA are also equipped to receive VHF (225 to 260 MHz) and UHF (1435 to 1540 MHz) telemetry.

USB systems were originally positioned around the world to provide optimum coverage of Apollo program orbits. The smaller 9-meter systems provided coverage of the earth orbit phases and limited support at lunar distances, while three 26-meter systems were positioned to permit continuous coverage at lunar distances. One of the 26-meter systems (Honeysuckle Creek, Australia) has been transferred to the Deep Space Network (DSN) operated by JPL, and plans are underway to redeploy other systems to provide more optimum coverage of the various orbits of projected future missions. Table 1-2 indicates current and planned locations of USB systems.

3.2.1.2 Antenna System Description. Typical USB antenna systems are shown in figures 3-1, 3-2, and 3-3. The systems employ monopulse autotrack principles to generate error signals for application to an antenna servo system, and thereby maintain the antenna pointed toward the spacecraft-transmitted signal. The system can perform this autotrack function with either phase or Frequency Modulated (FM) signals.

To aid in initial signal acquisition a second antenna operating mode may be used. This "program mode" uses orbital prediction data prepared in advance to continuously point the antenna toward the spacecraft; when the spacecraft signal is detected the autotrack mode described above would normally then be selected. The program mode operates by comparing angle readouts from encoders mounted on the antenna axes with predicted values, and generating corresponding error signals to drive the antenna servo. This function is accomplished by the Antenna Position Programmer (APP) which, in turn, uses data prepared on station from acquisition messages transmitted to the station. Initial acquisition of the spacecraft RF signal is facilitated by a small wider beamwidth acquisition parabolic antenna mounted at the apex of the 9- and 26-meter land-based antennas, and on the periphery of the shipboard antenna. Other antenna operating modes include manual, slew, slave, scan, and test.

Figure 3-1. Typical 4.3-meter (14-ft) USB Antenna (Former GRARR-1)

The X-Y mount is capable of tracking through zenith but has a gimbal restriction keyhole near the horizon. This restriction is generally oriented north to south on 9-meter antennas and east to west on 26-meter systems. The shipboard az-el mount has a keyhole at zenith. Antenna coverage patterns are further restricted at most stations by the surrounding terrain. Polar plots showing these restrictions as a function of antenna azimuth are available for most antennas. Additional USB antenna characteristic data is presented in table 3-1.

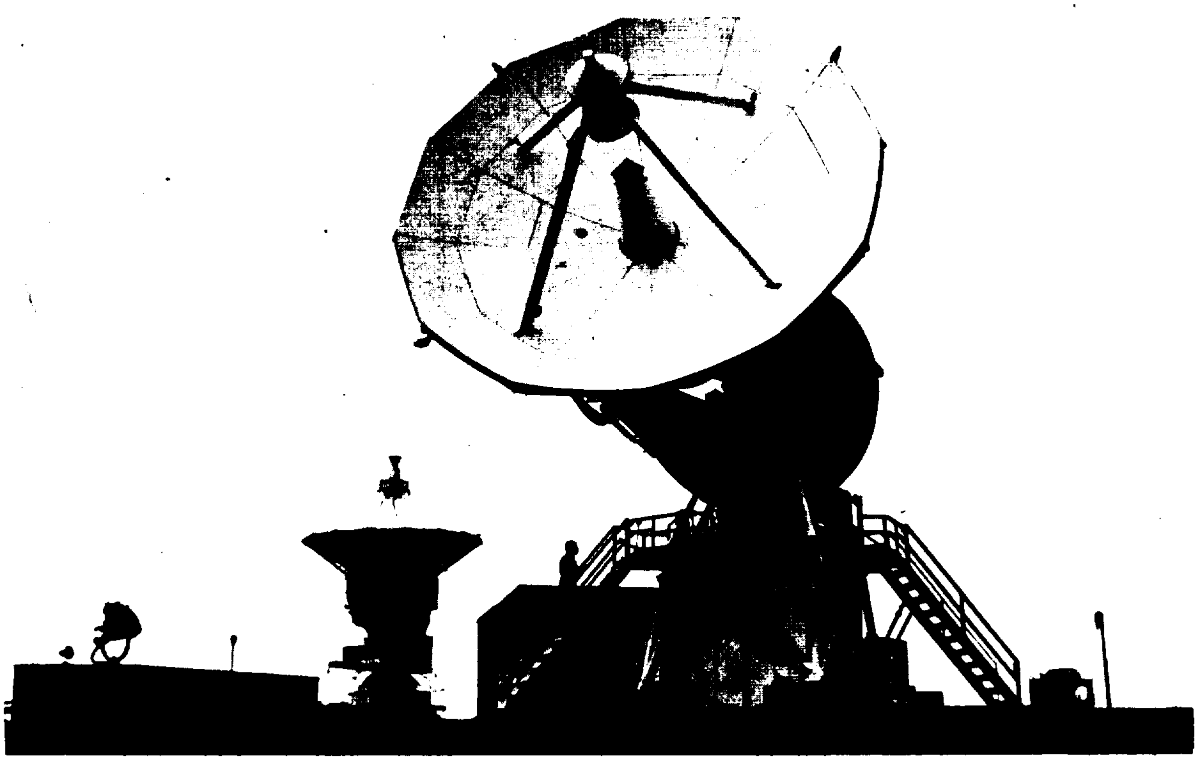


Figure 3-2. Typical 9-meter (30-ft) USB Antenna

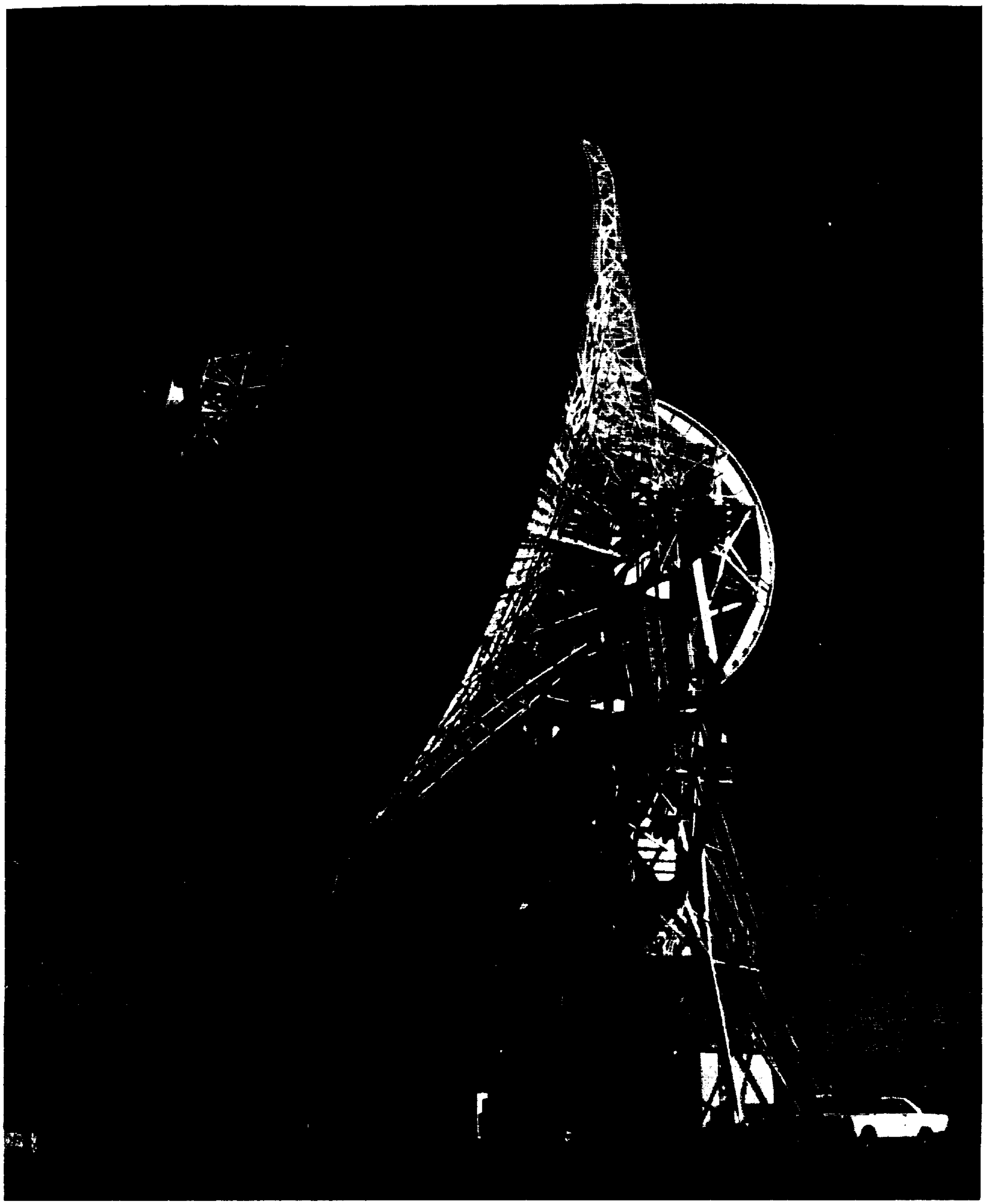


Figure 3-3. Typical 26-meter (85-ft) USB Antenna

Table 3-1. USB Antenna Characteristics

Antenna	Station	Gain	Beamwidth (deg) (3 dB)	Polarization	Mount Orientation	Acq System	Acq Gain (dB)	Acq Beamwidth	Rate Deg/Sec	Acceleration Deg/Sec^2
9m (30-ft) X-Y	ACN, AGO, BDA, CRO, CYI, ETC, GDS, GWM, HAW, MIL, ORR(1)	Rx 44 dB Tx 43 dB	1.0	RCP/LCP(2)	+X east +Y north (3)	Apex mounted 1m	22.0	10	4	5
26m (85-ft) X-Y	MAD, GDS	Rx 53.5 dB Tx 51 dB	0.3	RCP/LCP(2)	+X south +Y east	Apex mounted 2m	25.5	5	3	5
9m (30-ft) Ship Az-el	VAN	Rx 44 dB Tx 43 dB	1.0	RCP/LCP(2)	Az-el	Edge-mounted 1m	22.0	10	50 az 30 el	50
4.3m (14-ft) X-Y	ROS, TAN, QUI(4)	Rx 35 dB Tx 36 dB	2 to 2.5	Orthogonal linear, optimally combined in receiver	X-Y				5	0.2

Note

(1) A 9-meter system is currently being installed at ORR.

(2) Remote selectable polarization for receive and transmit.

(3) The 9-meter ERTS USB systems at ETC and GDS are oriented X south, Y east.

(4) CRO 4.3-meter system is being moved to QUI.

3.2.2 USB SYSTEM FUNCTIONS AND CAPABILITIES

The USB system is capable of providing the multiple support functions for command, telemetry, tracking (angle, range and range rate), and two-way voice communications, using frequencies for uplink between 2100 and 2120 MHz with a coherent down-link frequency between 2270 and 2300 MHz. The system is also capable of receiving wide-band transmissions with FM demodulator bandwidth to 20 MHz available. It is important to note that the system currently configured is capable of receiving downlink signals throughout the 2200- to 2300-MHz frequency range, but, because of the limited uplink operating band, coherent operation is restricted to the upper 30 MHz of the receive band. Coherent operation with a compatible spacecraft transponder is required if range and range rate measurements are to be made.

As noted earlier, the uplink transmission frequency band capability is being expanded, and will extend from 2025 to 2120 MHz when completed. Required transponder frequency ratio is 240/221; that is, the downlink frequencies are coherently translated in the spacecraft by 240/221 times the uplink frequency.

3.2.2.1 USB Uplink Description. Figure 3-4 illustrates several typical USB frequency spectra that are used in the Apollo program. The uplink spectrum illustrates the use of frequency modulated subcarriers at 30 and 70 kHz, which are phase modulated onto the S-band carrier along with a ranging code. In the case illustrated, voice and command information modulate the subcarriers. The uplink system also has been used with command modulation directly on the carrier, and system flexibility is such that other subcarrier frequencies could be used with only minor changes. For example, a 124-kHz subcarrier also has been used. The uplink system is fully compatible with the Spacecraft Command Encoder (SCE) system described in para 3.7 and will accommodate all the command modes noted therein. The ranging code is "turned around" by the spacecraft transponder and retransmitted on the downlink for use by the ranging system.

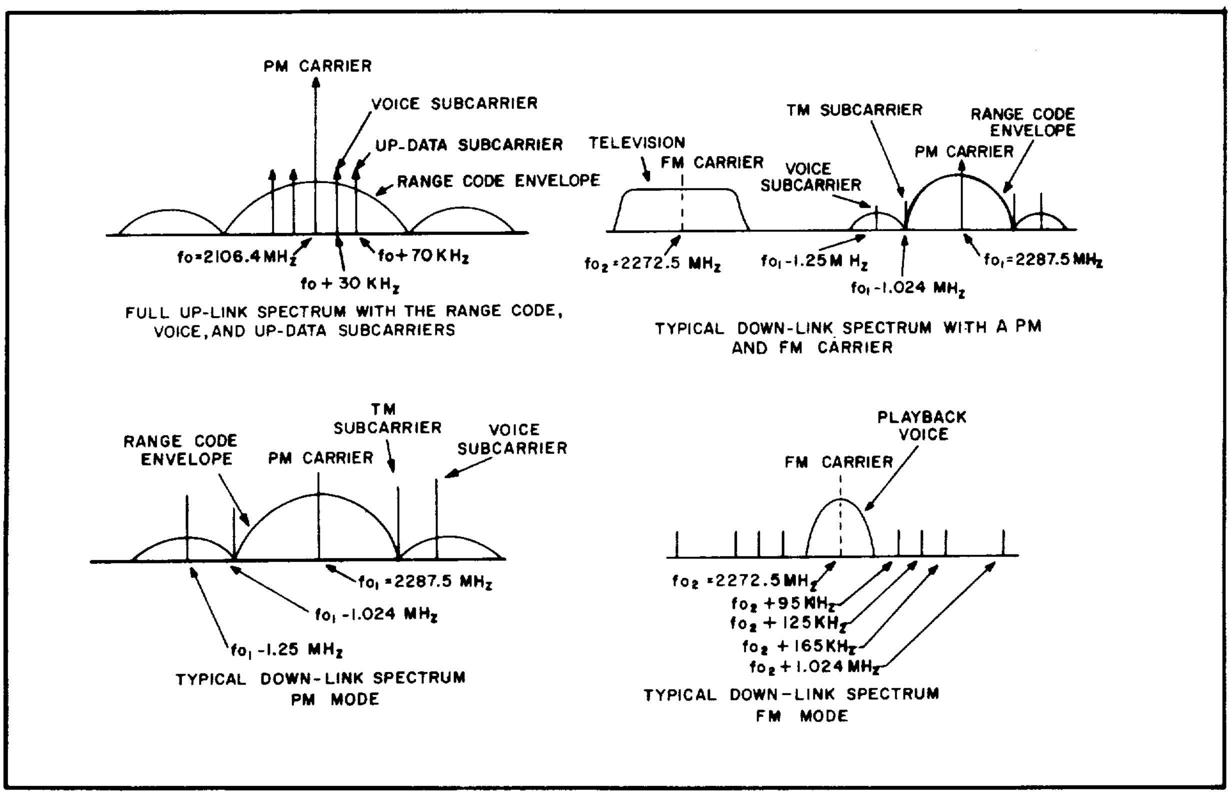


Figure 3-4. Typical Uplink and Downlink Frequency Spectra as used in the Apollo Program

Uplink transmitter power level is continuously variable from about 500 watts to a maximum of 20 kW. Two carrier frequencies can be transmitted simultaneously (except at Santiago) provided that they are within the instantaneous bandwidth of the power amplifier klystron (currently about 10 MHz but being expanded to 22 MHz). Lower power operation is required when transmitting two carriers unless the intermodulation products created at higher levels can be tolerated. Operation at 2 kW per carrier results in intermodulation products approximately 30 dB below the carrier level. It should be noted that the 26-meter USB systems were originally implemented with dual power amplifiers (vs only a single amplifier for the 9-meter systems) and a high-power combiner to permit simultaneous transmissions of two carrier frequencies at high-power levels. This capability is still available, but only within a limited frequency range.

The expansion of the uplink frequency range is being achieved through the addition of new tunable exciters and modifications to the power amplifier and antenna feed. The new exciters will include a provision for 1-MHz peak deviation FM in addition to Phase Modulation (PM) (3 radians peak deviation). Provision also is being made for carrier Phase Shift Key (PSK) modulation in anticipation of a 72 kb/sec (two 32-kb/sec delta modulation voice links and an 8-kb/sec command link) space shuttle program requirement.

3.2.2.2 USB Downlink Description. This section discusses the receivers and demodulation equipment commonly associated with the USB system. A discussion of the USB system front end including the parametric amplifier characteristics and system noise temperatures is presented in para 3.6.

The USB system normally includes four main receivers and is capable of receiving four downlink frequencies simultaneously provided that the transmitting sources are within the USB antenna beamwidth. Two of these receivers can be tuned across the 2200- to 2300-MHz frequency band, with FM mode IF bandwidths to 30 MHz permissible. The remaining two are limited to 5-MHz FM IF bandwidth and fixed frequency reception at frequencies in the range of 2270 to 2300 MHz. All four receivers have PM IF bandwidths to about 3.3 MHz. Normally the downlink carrier will be modulated with a composite signal consisting of ranging data and modulated subcarriers but, as with the uplink, data may be modulated directly on the carrier. The receivers can be operated in either an open-loop or closed-loop configuration with carrier tracking loop bandwidths ranging from 12 to 700 Hz when tracking a PM carrier in the closed-loop mode. Television or other wideband data is normally received as carrier FM with the receiver operating in the open-loop mode. FM demodulator bandwidth is 20 MHz. Typical downlink spectra are illustrated in figure 3-4.

At least two Signal Data Demodulator Systems (SDDS) are provided with each USB system to demodulate the various downlink signals. Carrier demodulation in the PM mode is accomplished in the USB receiver and the subcarriers are routed to the SDDS for baseband demodulation of voice or telemetry data. For FM, both carrier and subcarrier demodulation is accomplished in the SDDS, the FM being routed from the USB receiver at an IF of 50 MHz. Figure 3-5 is a block diagram of the fixed-frequency USB receiver along with the FM carrier demodulator and a fixed-frequency demodulator (1.024 MHz) that have been used extensively for the telemetry subcarrier in the manned flight program. (The tunable receiver is similar to the unit shown except for an additional IF [340 MHz] ahead of the 50-MHz IF.) The receiver can be operated also in conjunction with other existing demodulators. These demodulators are tunable over a frequency range from 1 kHz to 2 MHz and can accomodate PCM/PSK bit rates from 1 b/sec to 1 Mb/sec. Demodulated outputs are normally fed to the station bit synchronizers/demodulators for further processing. These systems are described in para 3.6.

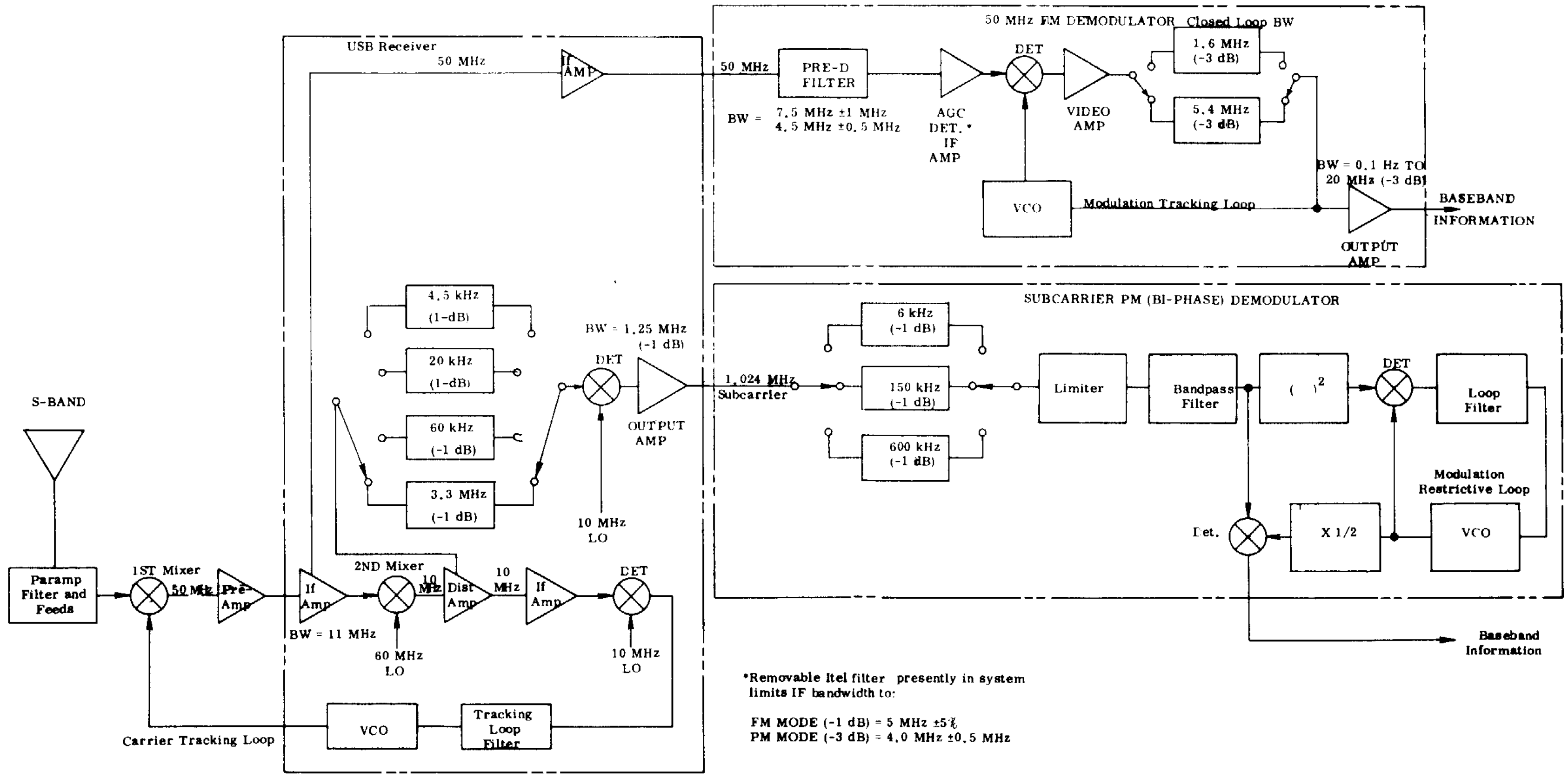


Figure 3-5. USB Single Receiver and Demodulator (Fixed Frequency)

Multifunction Receivers (MFR's) are being procured for use with the USB system as part of the standardization effort discussed earlier. The MFR already is being used in some STDN systems and its capabilities are described in para 3.6. This receiver will be used in conjunction with wideband downconverters (2200 to 2300 down to 400 to 500 MHz) to provide polarization diversity autotrack and data reception capabilities. Carrier demodulation of AM, PM, and FM signals is permitted with the MFR. Work to define recommended subcarrier frequencies for use with the USB system in this time frame has been completed recently and these results are available upon request.

3.2.2.3 USB Tracking Subsystem. The USB tracking subsystem determines and continuously updates the position of a spacecraft by measuring the antenna pointing angle, range, and range rate of the vehicle with respect to the station. Each USB system can determine the range and range rate of two vehicles simultaneously (provided that both are within the beamwidth of the single antenna) but can angle track only one vehicle at a time. Angle tracking is provided through the autotrack operation described in para 3.2.1.2; antenna-mounted shaft encoders provide the angle tracking information. The range and range rate operation is as follows:

a. Range and Range Rate. A digital ranging technique is used to determine spacecraft range. In this system, a pseudorandom binary code (termed a ranging code) is phase modulated on the S-band uplink carrier (possibly along with other uplink information as noted previously) and transmitted to the spacecraft. The transponder system within the spacecraft extracts the ranging code and applies it (PM) to the coherent downlink carrier which is transmitted back to the ground station receiver. A ranging receiver accepts the ranging data from the main USB receiver at a 10-MHz IF. Here a correlation process occurs wherein the received ranging code is compared with a time-shifted code provided by the ranging system and through this process, roundtrip time for the code is determined. The range to the spacecraft is derived from this information.

After range has been established, it is possible to disable the full code modulation (which results in sideband components up to 2 MHz from the carrier) and still maintain ranging by continuing to modulate the carrier with only a two-bit clock code. This limits the spectral distribution due to ranging to two single-spectral lines, 496 kHz above and below the carrier frequency. The maximum unambiguous ranging distance using this system is 800,000 kilometers and the maximum range tracking rate is 12,000 meters per second. Range and other USB system accuracy data are presented in table 3-2. The numbers given are typical of accuracies achievable for earth orbital operations and include errors due to geodetic uncertainties in the station locations and other environmental biases (e.g., refraction, drag, and earth potential). The angular accuracies given represent the maximum that might be expected for a given orbital pass; average angular accuracy over a period of time is somewhat greater than that shown.

Table 3-2. Representative USB Metric Tracking Accuracies

Characteristics	Bias	Noise
Range (meters)	36	5
Range Rate (mm/sec)	250	5.5 (1/6 sec)
Angle (degrees)	0.025	0.02

Spacecraft range rate (velocity) is determined by measuring the Doppler shift of the transponded carrier signal. This Doppler shift information is superimposed on a 1-MHz bias frequency and the resulting biased Doppler, or range rate signal, is applied to a Doppler counting system. The bias frequency provides sense information to allow determination of spacecraft radial direction of travel; a value less than 1 MHz indicates that the spacecraft is approaching while a greater value indicates that the radial velocity of the spacecraft is away from the station. The Doppler counting system is designed to handle plus or minus 180 MHz, biased about the 1-MHz frequency. Doppler is counted continuously throughout the tracking period (nondestruct); the number of Doppler cycles in any given time period is then representative of range rate for that period. The Tracking Data Processor (TDP) formats the Doppler information for transmission from the station.

The ranging system described is scheduled to be replaced with a new improved accuracy system which will be part of the standardized system scheduled for implementation throughout the network by the end of 1976.

In the new system, a number of different frequency tones will be modulated on the uplink carrier; the spacecraft transponder will return the signals on the downlink and the ranging system will determine range by measuring the phase shift of the tones. The higher frequency tones provide for system accuracy and lower frequencies for range ambiguity resolution. Frequencies are as follows: 500 kHz, 100 kHz, 20 kHz, 4 kHz, 300 Hz, 160 Hz, 40 Hz, and 10 Hz. Any one of the three highest frequency tones will be selectable as the highest accuracy tone, with the remaining tones being used for range ambiguity resolution. The 500-kHz tone provides highest accuracy but requires greater transponder bandwidth. The system is specified to provide unambiguous range to at least 500,000 kilometers. Since the lowest frequency tone provides range ambiguity resolution to only 15,000 kilometers, a PRN code will be used when greater range capability is required. This code will be modulated on the 4-kHz tone.

The specification of the new system requires a range instrument accuracy of 1 meter with a granularity of 0.15 meter. The current system instrument accuracy is about 6 meters with a 1-meter resolution.

b. USB Tracking Data Transmission. A Tracking Data Processor (TDP) is used to format angle, range, range rate, and time information along with station identification and equipment status information. This data may then be transmitted to the control center either by high-speed data lines or teletype or, alternatively, it may be recorded on magnetic or teletype tape. Generally, data for two vehicles can be transmitted simultaneously by alternately transmitting data frames for each vehicle. (Both vehicles, of course, must be within the single antenna beamwidth in order for tracking data to be generated for each vehicle.)

The tracking data is sampled at 10 samples per second for the high-speed data format and one sample every 6 seconds or one sample every 10 seconds for teletype transmission. The high-speed data format also includes a processor-generated polynomial error detection code and a synchronization pattern. The polynomial code is selectable at either 22 or 33 bits in length with one pattern in each frame of 240 bits. The teletype format does not employ the polynomial code and uses a frame length of 60 Baudot code characters. (Current plans are that high-speed tracking data transmission capability will be used only for launch support at Bermuda, Merritt Island, and Vanguard.)

Current plans are that a new computer-controlled Tracking Data Processor System (TDPS) will be installed in the network, the completion of which is scheduled in 1976. The normal mode of data transmission with this system will be near real-time teletype (TTY), although a high-speed interface also will be provided. This systems computer (PDP-11) will also perform functions now being accomplished by several systems, including the APP, antenna scan generator, and the antenna servo amplifier. It is expected that the TTY transmissions of this system will employ the American Standard Code for Information Interchange (ASCII) code discussed in para 3.9.3. Additional data regarding tracking and data acquisition formats is available upon request.

3.3 GODDARD RANGE AND RANGE RATE SYSTEM

3.3.1 GENERAL

The Goddard Range and Range Rate (GRARR) system was designed and implemented as an element of the original unmanned Space Tracking and Data Network (STADAN) primarily to provide spacecraft tracking for orbits where the interferometer tracking system was inadequate (refer to para 3.5). The original design included systems operating at both S-band and VHF frequencies; however, the S-band system is no longer operational. Portions of this equipment have been converted to be compatible with the USB system and are described in para 3.2. This section discusses the VHF GRARR system which is being used as originally designed. It is expected this system will also eventually be phased out consistent with current plans to vacate the VHF frequency band.

3.3.2 VHF SYSTEM DESCRIPTION

VHF GRARR systems are located at Rosman, Fairbanks, Tananarive, Santiago, and Carnarvon. When Carnarvon is closed in 1975, the VHF equipment will be relocated to Orroral Valley, and the S-band equipment will be relocated to Quito.

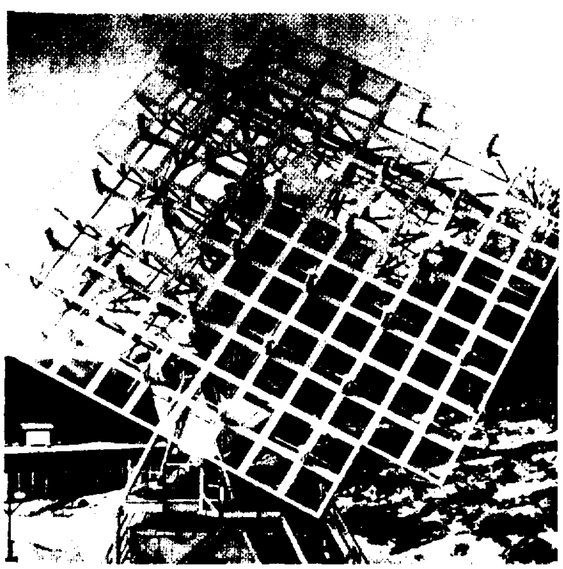


Figure 3-6. GRARR VHF Dipole Antenna

Major performance characteristics of the GRARR VHF antenna systems are similar although physical differences exist from station to station. Figure 3-6 illustrates the systems located at Fairbanks and Santiago. All the antennas are planar arrays with receive gain capabilities of about 21 dB and a beamwidth of 15 degrees. Polarization is switch selectable RCP, LCP, horizontal, or vertical. Diplexers are used to permit simultaneous transmission (148 to 150 MHz) and reception (136 to 138 MHz) as required for the ranging process. Antenna mounts are X-Y autotracking types. The GRARR systems at Carnarvon, Rosman, and Tananarive utilize the MFR described in para 3.6.4.3. Systems at Santiago and Fairbanks use original GRARR equipment receivers. Preamplifiers mounted on the antennas have a noise figure of about 3 dB.

3.3.3 GRARR FUNCTIONS

3.3.3.1 General. The GRARR system, when operated in conjunction with a suitable spacecraft transponder, is a high-precision tracking system used for determining the range, range rate of, and direction to a spacecraft in earth orbit. The system has been used successfully also at lunar orbit distances. The tracking data is recorded on punched paper TTY tape. This tape is manually relayed to teletype machines for subsequent transmission to GSFC where it is used with other data to determine the orbital parameters of a spacecraft. Transmitter power output is variable up to 10 kW.

The GRARR system can be used also for telemetry and command (136 and 148 MHz, respectively) functions; however, since its primary use is tracking (range and range rate), only this function will be described here.

3.3.3.2 Range. Range to the spacecraft is determined through the use of sidetones modulated on the uplink and downlink carriers. The time delay between ground-transmitted sidetones and transponder-returned sidetones is directly proportional to the two-way range between the tracking antenna and the satellite. The sidetone frequencies are 20 and 4 kHz, 800, 160, 32, and 8 Hz. The 20-kHz tone is the highest frequency tone available and establishes system resolution. The lower frequency tones are used to resolve range ambiguities. The four lowest frequency tones are complemented on the high side of the 4-kHz tone (producing frequences of 4800, 4160, 4032, and 4008 Hz) for transmission to the spacecraft. This eliminates modulation components close to the carrier which would degrade carrier acquisition and tracking. The lowest tone available, 8 Hz, provides for an unambiguous range to 18,737 kilometers.

When greater range measurements are required, a hybrid ranging mode is employed. In this mode, an ambiguity resolving pseudorandom digital code is biphase modulated on the 4-kHz sidetone, the four minor tones having been removed. A correlation process is used to determine the round trip travel time of this ranging code and hence, the range to the spacecraft. The code is constructed to provide an unambiguous range of approximately 1.2 million kilometers.

3.3.3.3 Range Rate. Range rate is determined from the two-way Doppler shift of the uplink carrier frequency. In order to measure this Doppler shift, it is necessary to maintain coherence of the uplink frequency through the transponder and back to the ground receiver where it is compared in frequency against a continuing sample of the uplink frequency in the range rate extraction unit. The range rate extraction unit measures Doppler by determining the elapsed time of a preset number of cycles of the sum of the Doppler shift plus a known frequency offset. The maximum expected two-way Doppler is ±20 kHz at the VHF frequencies used.

A crystal type transponder is utilized in the spacecraft. The transponder receives the GRARR transmitted signal (approximately 148 MHz) and heterodynes it to a low IF (667 to 920 kHz) which in turn is phase modulated onto the downlink carrier (approximately 136 MHz). Coherence is maintained by deriving the downlink carrier frequency from the same reference oscillator that was used in the heterodyning operation. Figure 3-7 shows typical uplink and downlink spectra.

3.3.4 SYSTEM ACCURACY

GRARR system accuracy is illustrated by the curves shown in figures 3-8 and 3-9. Figure 3-8 presents range errors as a function of tracking bandwidth signal-to-noise ratio (S:N) for two bandwidth settings and Doppler conditions as indicated. Figure 3-9 provides range rate accuracy data using sample rate and bandwidth as parameters.

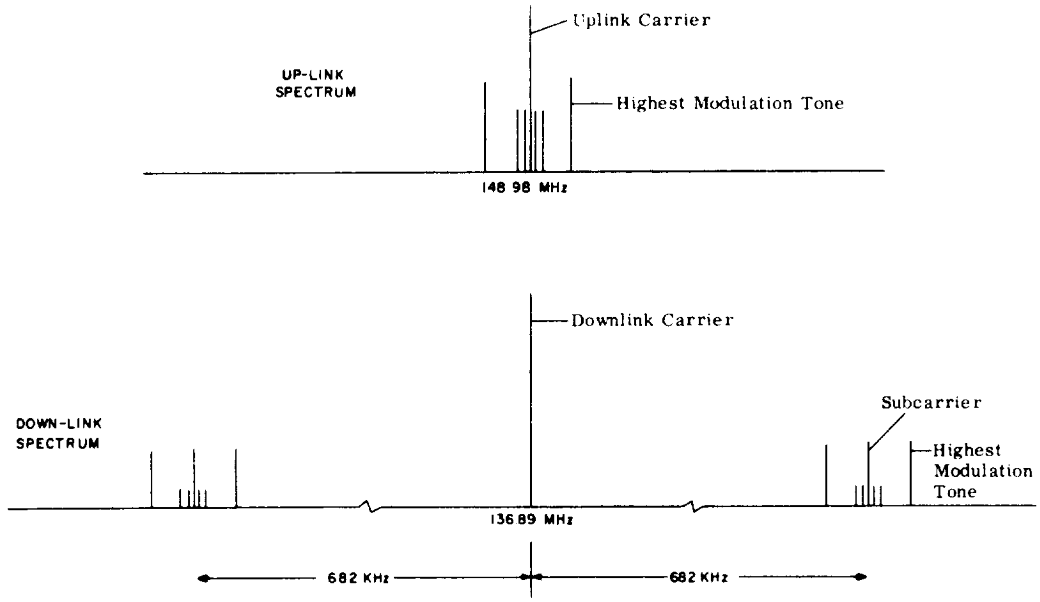


Figure 3-7. VHF-band Spectra of Goddard Range and Range Rate System Uplink and Downlink Signals

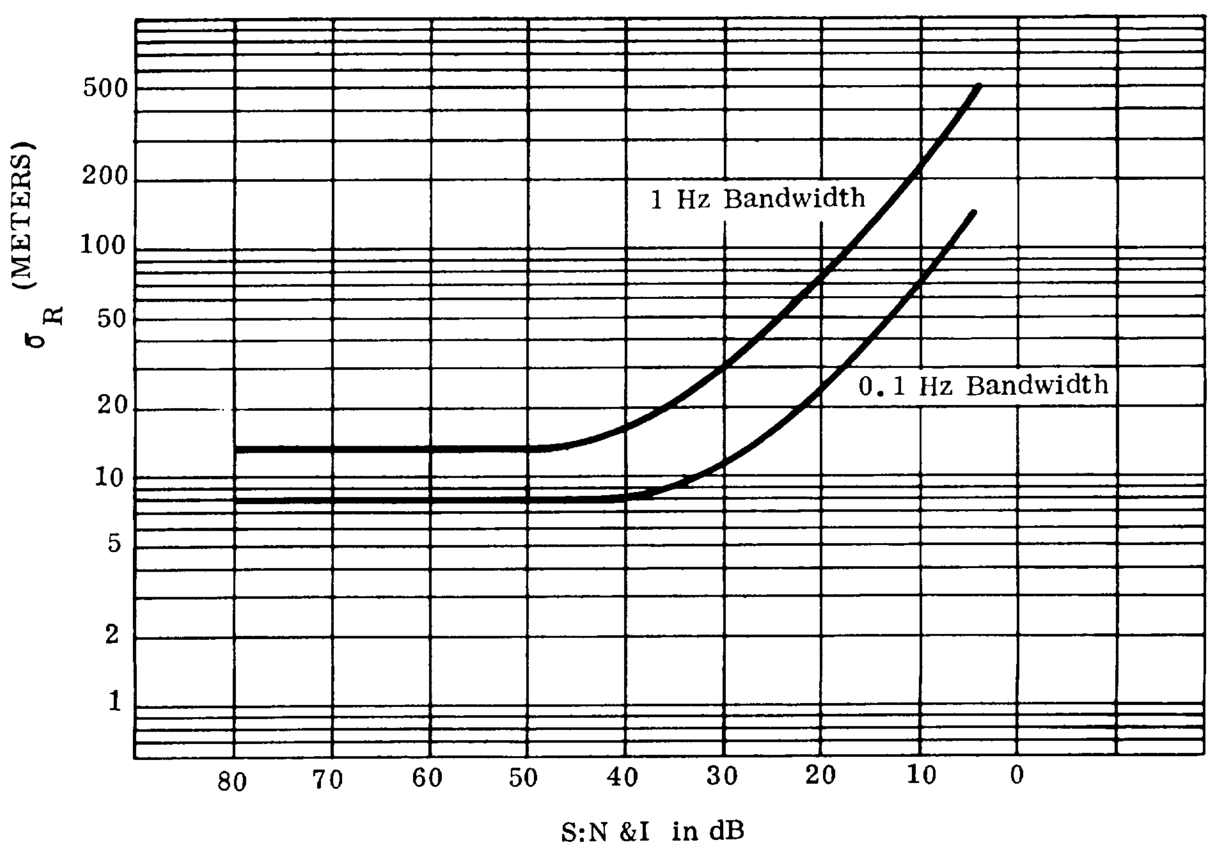


Figure 3-8. VHF Range Instrumental Accuracy (0.1-Hz Range Tone Tracking Bandwidth with no Doppler and 1-Hz Bandwidth with Maximum Doppler)

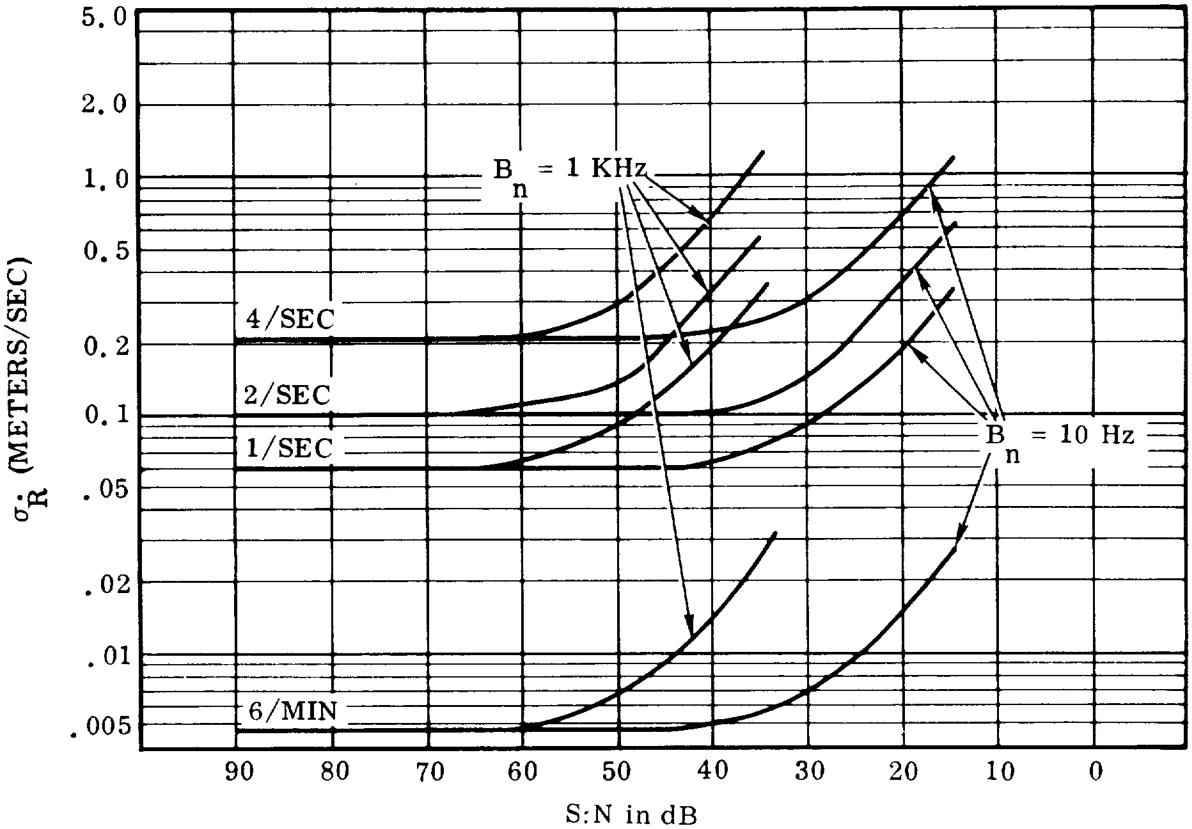


Figure 3-9. VHF Range Rate Instrumental Accuracy

3.4 C-BAND RADAR

The STDN is equipped with two models of C-band radar: AN/FPS-16 and AN/FPQ-6. These systems provide vehicle position data (range, azimuth, elevation, and time) to the computational center for impact prediction and orbit determination. Table 3-3 gives the location and characteristics of the radars. As is indicated by the table, there is some variance in the characteristics of the individual radars even though they have the same model designator. For example, a significant variance in the AN/FPS-16 models is the different antenna size. This, of course, results in different gain and beamwidth characteristics.

Table 3-3. Radar System Characteristics

Station	Type Radar	Power	Antenna Size (Ft)	Antenna Gain (dB)	Antenna Beamwidth (degrees)	Range and System Capability	Aux Trk[2] IRACQ[3]	Circular Polarization Capability[1]	Aux Computer
BDA	AN/FPQ-6	3MW	29 (8.8m)	51	0.4	ADRAN 32 kmmi	Aux Trk	Console Select	4101B
HAW	AN/FPS-16	1MW	12 (3.6m)	43	1.2	DIRAM 32 kmmi	IRACQ	Man	1218
TAN	AN/FPS-16	1MW	16 (4.9m)	46	0.8	IDRAN 32 kmmi	Aux Trk	Console Select	4101A
VAN	AN/FPS-16	1MW	16 (4.9m)	46	0.8	ADRAN 32 kmmi	Aux Trk	Console Select	642B

Note

1. All systems shown also have linear polarization capability.

2. Auxiliary Range Tracking. Provides automatic range acquisition after angle acquisition of target.

3. Instrumentation Radar Acquisition System. Acquisition aid which includes Aux Trk and adds circular, spiral, raster, and rectangular scan capability.

Each of the radars is similar in that the receive systems employ parametric amplifiers with a noise figure of about 3.5 dB, all have digital designate capability, and all operate in the 5400- to 5900-MHz band. (The AN/FPS-16 transmits in the range of 5450 to 5825 MHz; the AN/FPQ-6 from 5400 to 5900 MHz.) A number of computer systems are used with the radar as indicated in table 3-3. The computers process and format tracking data, provide antenna pointing data, and drive plotting boards.

The tracking data may be recorded on magnetic tape or transmitted to GSFC via high-speed data lines or teletype. This data is sampled at 10 samples per second for the high-speed data format, one sample per second or one sample per 2 seconds for the Vanguard, and one sample every 6 seconds for the teletype format. The high-speed data format also includes a computer-generated polynomial error detection code 33 bits in length, and a synchronization pattern. The error code and pattern are contained in each sample (frame) of 240 bits. The Vanguard high-speed data sample is 600 bits in length and includes USB as well as C-band radar information.

The radars are precision monopulse tracking systems designed specifically for missile range instrumentation, with the AN/FPQ-6 having somewhat greater capability due to greater antenna size and radiated power. The maximum range tracking rate for either system is 20,000 yards/sec and the antenna tracking rates are as follows:

Radar	Azimuth	Elevation
AN/FPS-16 (12-ft Dish)	750 mils/sec	400 mils/sec
AN/FPS-16 (16-ft Dish)	800 mils/sec	450 mils/sec
AN/FPQ-6	500 mils/sec	500 mils/sec

Typical range and angle data residuals for the AN/FPQ-6 and AN/FPS-16 are given in table 3-4. An AN/FPS-16 at Bermuda and an AN/FPQ-6 at Carnarvon have recently been deactivated.

Table 3-4. C-band Radar Residuals

Radar	Errors	Typical Angle Data Residuals	Typical Range Data Residuals
AN/FPQ-6	Bias	0.01 degree	20 meters
	Noise	0.01 degree	10 meters
AN/FPS-16	Bias	0.02 degree	20 meters
	Noise	0.02 degree	10 meters

3.5 INTERFEROMETER TRACKING SYSTEM AND MINITRACK OPTICAL TRACKING SYSTEM

3.5.1 INTERFEROMETER TRACKING SYSTEM

A number of stations have an interferometer tracking system. The system, named Minitrack, receives spacecraft transmissions in the 136- to 137-MHz range and determines spacecraft direction by measuring the angle of arrival of these signals. This system was conceived in the late 1950's and used in support of the U. S. Vanguard satellite program. It is expected that the use of the interferometer tracking system will be discontinued consistent with present plans to phase out use of the 136-MHz receive frequency.

Interferometer systems operate on the principle that the phase angle of a signal received by two separate fixed antennas will vary as a function of the angle between the baseline of the two antennas and the transmitting source. By measuring the phase difference, this angle, or direction consine, may be computed. The basic principle is illustrated in figure 3-10.

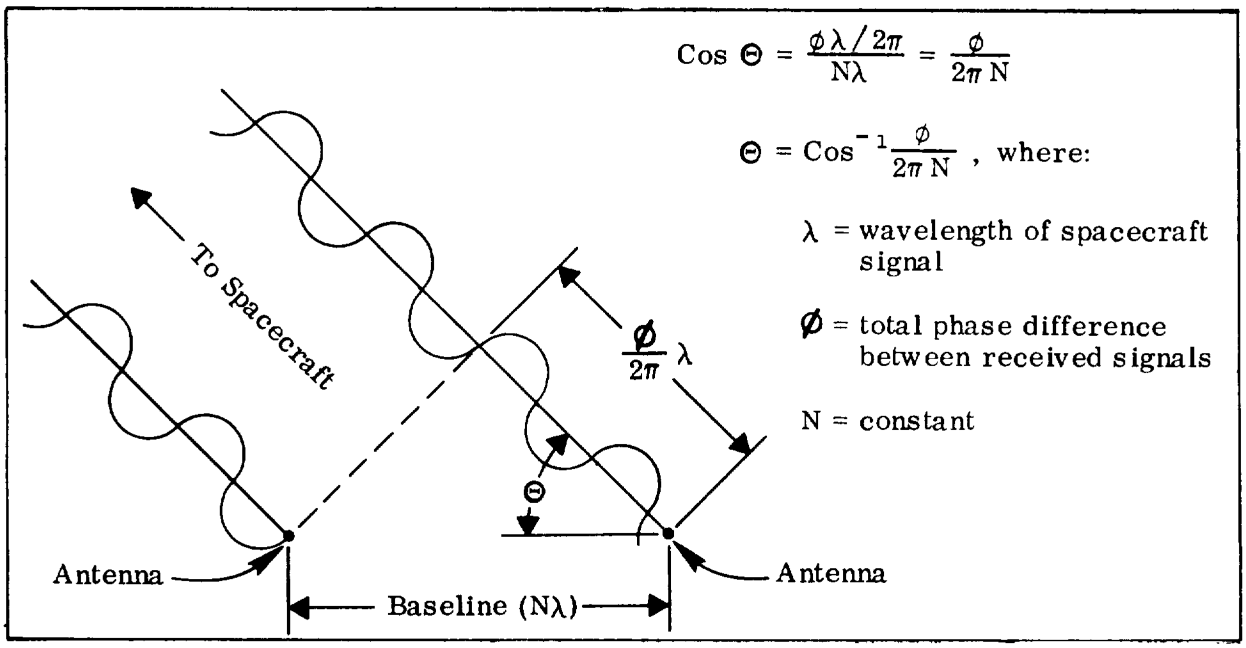


Figure 3-10. Interferometer Principle

By using two orthogonal baselines (four antennas), two direction cosines which are required to fully define the direction to the spacecraft may be obtained. In actual practice, a number of antennas are used, as illustrated schematically in figure 3-11, and pictured in figure 3-12. Figure 3-11 shows eight "fine" antennas with baseline lengths of 46 or 57 wavelengths, and a group of five "ambiguity" antennas. As implied, the fine antennas provide high-resolution phase measurements, but since the phase readings repeat for each wavelength of path difference, an ambiguity regarding the total phase difference results. This is resolved using the ambiguity antennas in various combinations.

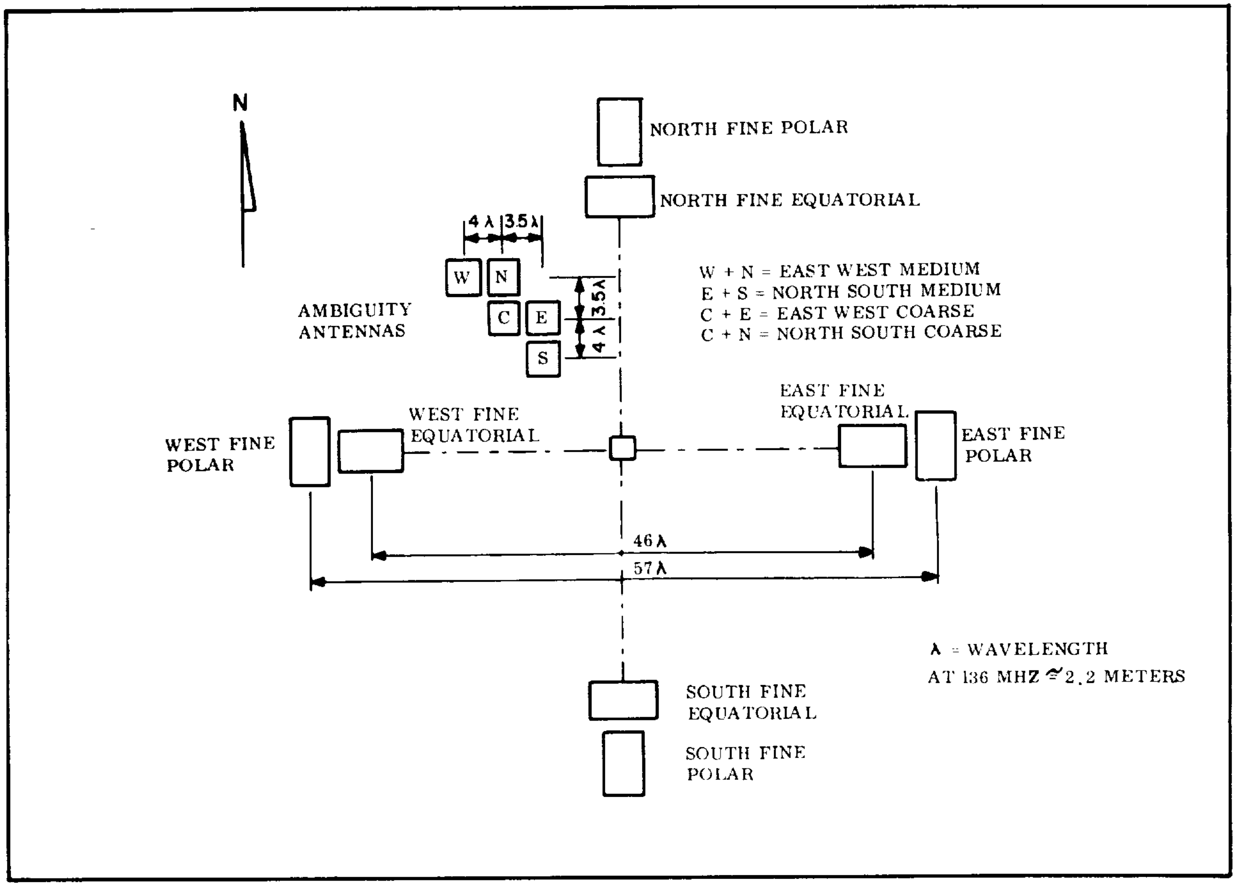


Figure 3-11. Interferometer Antenna Field Layout, Plan View

Two fine antennas are required at each end of the fine antenna baselines because of antenna gain consideration. The set of four antennas labeled "polar" have fan-shaped reception patterns oriented east-west (approximately 76 deg by 11 deg 3-dB beamwidth) and this set is used for polar and other high-inclination orbit spacecraft. The other set of antennas marked "equatorial" is switched in for use with equatorial or low-inclination orbit spacecraft. The equatorial antennas have the same characteristics as the polar antennas, except the equatorial fan beam is oriented north-south. Fine antenna gain is about 16.3 dB.

Ambiguity antennas are combined to form two sets of orthogonal baselines termed medium and coarse, as indicated in figure 3-11. Ideally, for ambiguity resolution, a coarse baseline of one-half wavelength is needed. This reading would then be used to resolve the readings of progressively longer baselines system. The physical size of the antennas used prohibits this close spacing and instead they are separated, as indicated, by 4 and 3.5 wavelengths. An equivalent 0.5-wavelength baseline is obtained by subtracting phase readings of the 3.5-wavelength baseline system from the 4-wavelength system; similiarly, a 7.5-wavelength baseline is obtained by addition. The 0.5-wavelength baseline phase is used to resolve the ambiguity of the 4.0-wavelength baseline phase which, in turn, resolves the ambiguity of the 7.5-wavelength baseline phase. Finally, this data is used to identify the integral number of wavelengths of path difference on the fine atennas baseline so that the total phase difference may be determined for use in the basic interferometer equation given in figure 3-10. It should be noted the ambiguity antennas have a beamwidth of 78 deg by 106 deg (6.4-dB gain) and the same antennas are used for both polar and equatorial orbits.

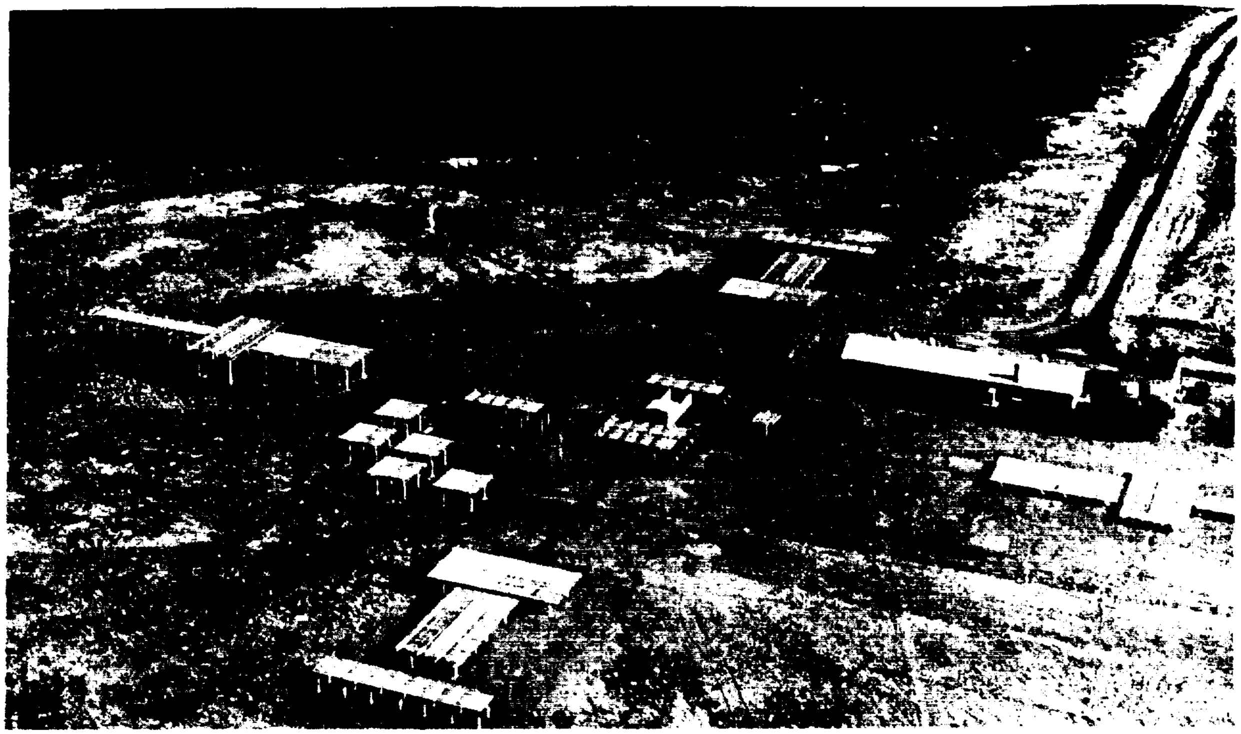


Figure 3-12. Minitrack Antenna Layout

The Minitrack receiver accepts signals from each antenna pair (six pairs of two each coarse, medium, and fine) and provides a 100-Hz output for each pair, whose phase is proportional to the phase difference in the signal received at the two antennas. These phase measurements are used to determine the direction cosines discussed. A seventh receiver channel is used for calibration. With a properly calibrated system, angular errors in the order of 0.2 milliradian can be expected.

3.5.2 MINITRACK OPTICAL TRACKING SYSTEM

The Minitrack Optical Tracking System (MOTS) is composed of a 1000-mm focal length lens astrographic camera (200-mm aperture) which is located in the exact center of the fine beam arrays of the antenna system. Being equatorially mounted, the camera is sidereally driven, allowing images of faint celestial objects to build up on a film emulsion. Depending upon the emulsion used, objects of approximately 13th magnitude can be photographed with exposure times of 5 minutes. The images are recorded on Kodak 8 by 10 by 0.06 inch glass plates. The star field presented is a circular 10-degree field of view.

In the past, the camera has been used both for interferometer calibration and for optical tracking of satellites. In addition, it is used to photograph astronomical objects (e.g., Comet Kohoutek). Interferometer calibration was accomplished by photographing an airborne flashing light against a background of stars while simultaneously receiving and tracking a 136-MHz signal from the same airborne source.

Current plans are to discontinue this method of calibration as it has been determined that computerized evaluations of tracks of targets of opportunity will yield equally satisfactory calibration data. The position of a comet as obtained from one carefully reduced plate is accurate to about 3 arc seconds. MOTS's are located at each Minitrack location (refer to table 1-2) and there is one at the Rosman, North Carolina station.

3.6 TELEMETRY

3.6.1 GENERAL

The STDN has the capability to receive, demodulate, process, and record spacecraft data telemetered on a number of frequency bands and using any one of the several modulation schemes. The locations of various telemetry antenna systems and basic receive frequency capabilities of each station are presented in table 1-2. Note that all stations except Winkfield, England, are capable of 2200- to 2300-MHz frequency band reception, and most also have the capability to receive signals in the 136- to 138-MHz band. Stations with the multiband parabolic telemetry antennas can receive signals also in the 400- to 402-MHz band and the 1750- to 1850-MHz band. (Rosman and Fairbanks are the only stations currently fully instrumented for 1750 and 1850 MHz.) Stations used in support of manned flight are also capable of receiving signals in the 225- to 300-MHz band. Current plans are that use of receive frequencies other than those in the 2200- to 2300-MHz band will gradually be discontinued, and corresponding network capabilities will be phased out.

The STDN stations are equipped to receive various types of telemetry data. Pulse Code Modulation (PCM) is the predominant form of data coding, and accordingly the network is well equipped to receive and demodulate PCM data. Other data handling equipment available at various stations can process Pulse Amplitude Modulation (PAM), Pulse Duration Modulation (PDM), Pulse Frequency Modulation (PFM), and standard IRIG Frequency Division Multiplex (FDM) transmissions. Flexibility to receive either AM, PM, or FM signals is provided by the Multifunction Receiver (MFR) now installed at some stations and scheduled for all stations.

Standards for telemetry are described in the Aerospace Data Systems Standards, available from the Aerospace Data Standards Office, Code 730.4.

3.6.2 TELEMETRY ANTENNAS

3.6.2.1 General. A number of different antenna systems are used for telemetry reception within the STDN. For convenience, the antennas are classed as parabolic or array types in the following brief description.

3.6.2.2 Parabolic Antennas. The Unified S-band (USB) system used extensively for telemetry reception (refer to para 3.2), utilizes either a 26-meter or a 9-meter diameter parabolic antenna. Many stations have parabolic antennas which are used solely for telemetry reception (i.e., no uplink capability), generally with multiple frequency band (136, 400, 1700, and 2200 MHz) capability. These antennas generally have X-Y mounts and are either 26 meters, 12 meters, or 4.3 meters in diameter. The USNS Vanguard has a 9-meter multiple frequency band (225 to 260 MHz, 2200 to 2300 MHz) parabolic antenna (in addition to a 9-meter USB antenna) and a similar antenna has been installed at Bermuda. The ARIA 2-meter antenna has reception capability in the 225- to 300-, 1435- to 1530-, and 2200-to 2300-MHz bands. Vanguard telemetry antennas have az-el mounts.

Generally, all of these antennas are capable of monopulse autotrack operation in each of the bands for which telemetry reception is possible, except that the 4.3-meter system must be manually steered or slaved to another on-station antenna. (Only one 4.3-meter telemetry antenna is currently in operation and it is normally slaved to an on-station 4-element quad-Yagi autotracking antenna. Both these antennas have az-el mounts.) USB antennas are illustrated in figures 3-1, 3-2, and 3-3. Figures 3-13 and 3-14 show the 26-meter and 12-meter multiband telemetry antennas. Table 3-5 indicates the multiple frequency band capabilities and corresponding system parameters which characterize the major STDN telemetry antennas.

PRECEDING PAGE BLANK NOT FILMED

Preceding page blank

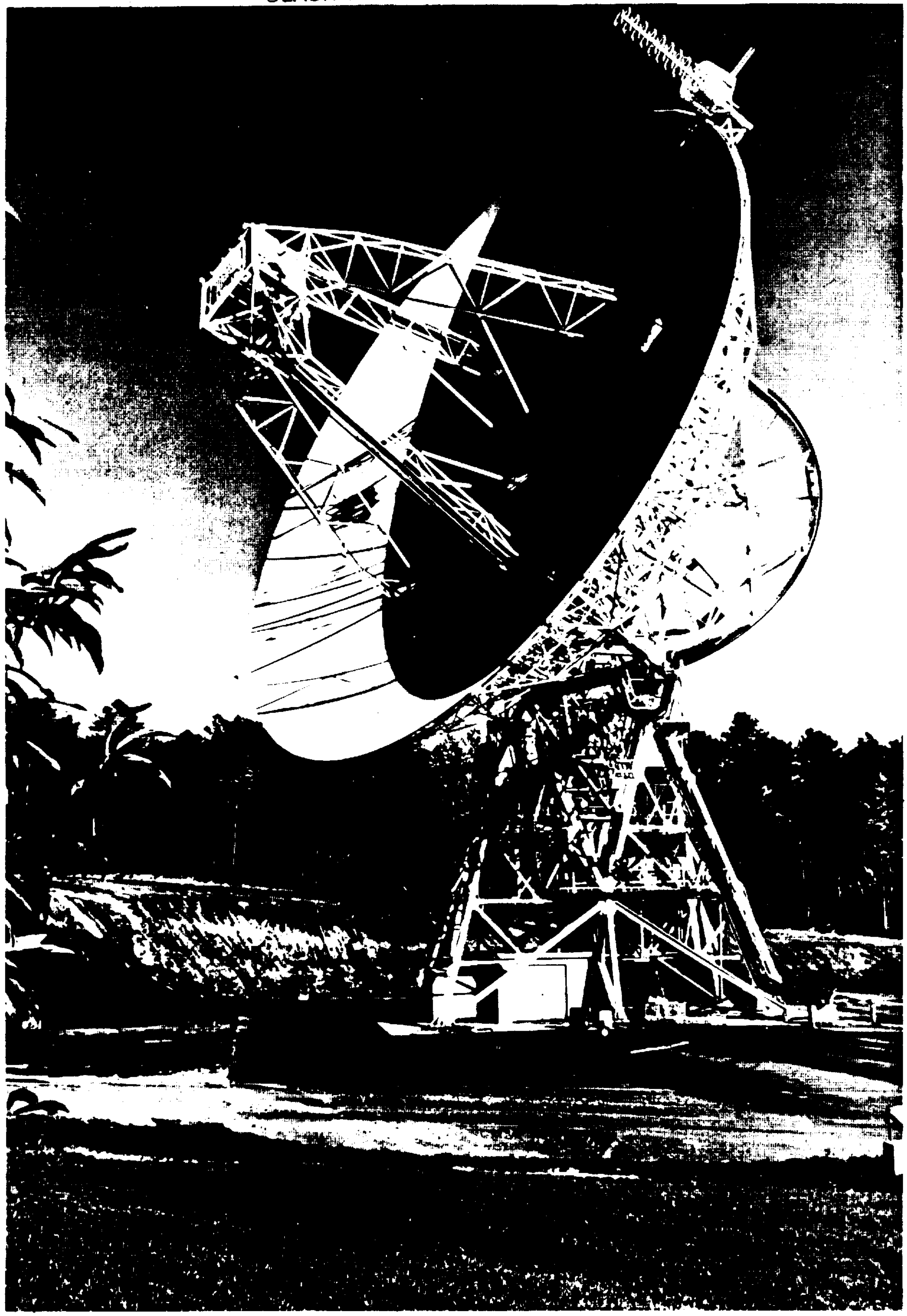


Figure 3-13. 26-meter (85-ft) Multiband Telemetry Antenna

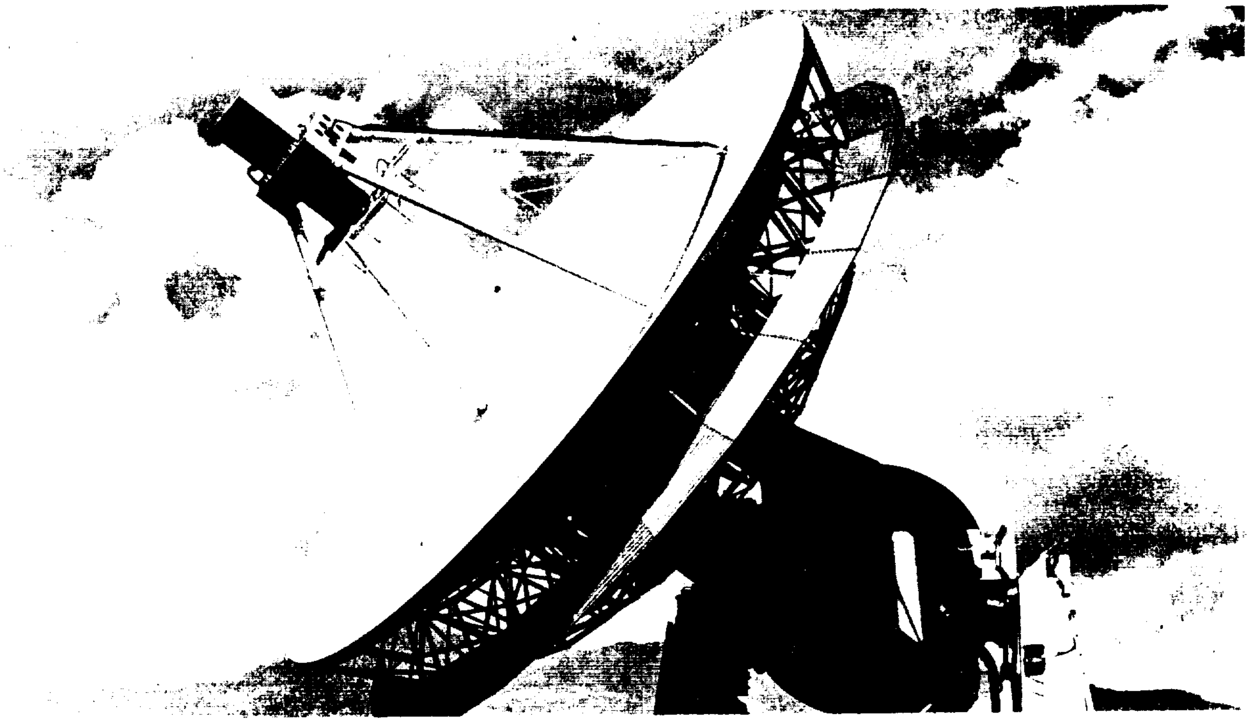


Figure 3-14. 12-meter (40-ft) Multiband Telemetry Antenna

3.6.2.3 Array Antennas. The antenna most widely deployed for receiving the 136-MHz frequency is the Satellite Automatic Tracking Antenna (SATAN). It is (or will be) deployed at most STDN stations as indicated in table 1-2. This antenna has an X-Y mount, a nominal gain of 21 dB, is a 136- to 138-MHz phase-monopulse autotrack array, and consists of a 16-Yagi structure supported by a square frame (see figure 3-15). Additional antennas utilized primarily for data acquisition at the 136-MHz frequency include the 9-Yagi array antenna shown in figure 3-16 with an 18-dB gain, and a dipole array with an 8-dB gain (130 MHz) aboard the Vanguard. These antennas do not have autotrack capability. The 9-Yagi array uses 8 elements for telemetry reception; the 9th element is used for command. As indicated earlier it is planned to eventually discontinue use of the 136-MHz frequency band and use of most of these antennas will eventually be discontinued.

Figure 3-15. SATAN 16-Yagi Receive Antenna

Frequencies in the 225- to 260-MHz band are used for manned space flight telemetry support. Array type antennas which receive these frequencies are the retrofitted Automatic Gimballed Antenna Vectoring Equipment (AGAVE) antenna and the 18- and 32-element Telemetry Tracking (TELTRAC) antennas which have az-el mounts.

Table 3-5. STDN Telemetry Receiving Antenna Characteristics

Antenna[1]	Frequency (MHz)	Gain (dB)	Beam-width (deg)	Polarization
26m (85') TLM Multiband	136	27.4	7x10.5	Linear diversity
	400	37.1	2.5	Linear diversity
	1700[2]	50.2	0.6	Linear diversity
	2250	52.5	0.3	Linear diversity
12m (40') TLM Multiband	136	16	13	Linear diversity
	400	30.6	7	Linear diversity
	1700[2]	43.7	1	Linear diversity
	2250	46.0	0.5	Linear diversity
9m (30') TLM (4-1)	2250	35	1	RCP, LCP selectable
	225	18	8.5	RCP, LCP selectable
4.3m (14') TLM	400	22	9x13	RCP, LCP vertical or horizontal
26m (85') USB	2250	53.5	0.3	RCP, LCP selectable
9m (30') USB	2250	44	1.0	RCP, LCP selectable
4.3m (14') USB[3]	2250	35	2 to 2.5	Orthogonal linear-optimally combined in receiver
SATAN 16-Yagi	136	21	13	RCP, LCP vertical or horizontal
TELTRAC (18-element dipole array)	225	19	20 Az 14 El	RCP, LCP simultaneous
TELTRAC (32-element dipole array)	225	21.5	14	RCP, LCP simultaneous.
Quad Helix Retrofit AGAVE	225	18	20	RCP, LCP not selectable
9-Yagi	136	18	20	RCP, LCP vertical or horizontal
Ship 4-2	260	12		RCP, LCP selectable
	135	8		RCP, LCP simultaneous
ARIA 7'	225	10.7	40	Linear or circular diversity
	1500	22.4	8	RCP, LCP simultaneous
	2250	27.2	4.5	RCP, LCP simultaneous

Note

[1] Antenna locations are tabulated in section 1.

[2] Instrumented only at ULA and ROS.

[3] Formerly GRARR antennas.

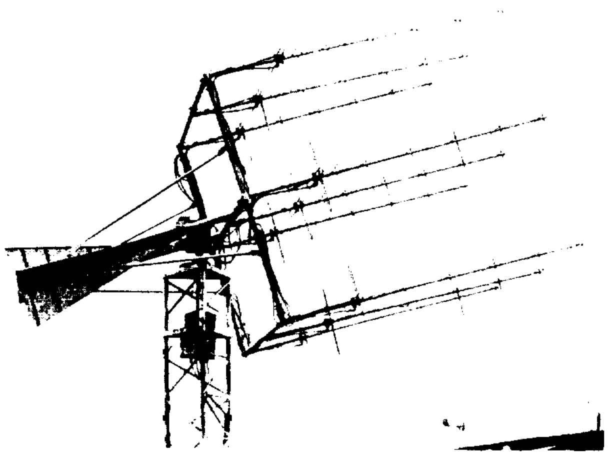


Figure 3-16. 9-Yagi Array (Center Element Command)

The AGAVE is a quad-helix array mounted on a retrofit type 584 or 8417 pedestal and has a minimum gain of 18 dB. It is capable of auto-track operations and signal reception, including voice, in the 225- to 260-MHz frequency band, and voice-only operation in the 280- to 300-MHz band. Monopulse tracking systems are employed with the TELTRAC and AGAVE antennas, and the tracking receivers are capable of operation in either phase-lock or cross-correlation modes. Both systems are capable also of manual or slave (to other on-station antennas) mode of operation. As implied, these antennas generally contain the necessary equipment to provide for simultaneous telemetry and A-G voice communications. The TELTRAC antennas have gains of 19 dB and 21.5 dB minimum for the 18-element and 32-element dipole array, respectively. TELTRAC and AGAVE antennas are shown in figures 3-17 and 3-18, respectively. It is currently planned to discontinue support in the 225- to 300-MHz (P-band telemetry and VHF A-G voice) band by late 1975.

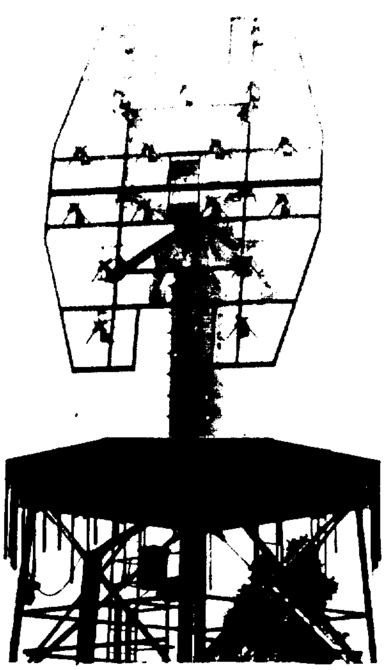


Figure 3-17. TELTRAC Antenna

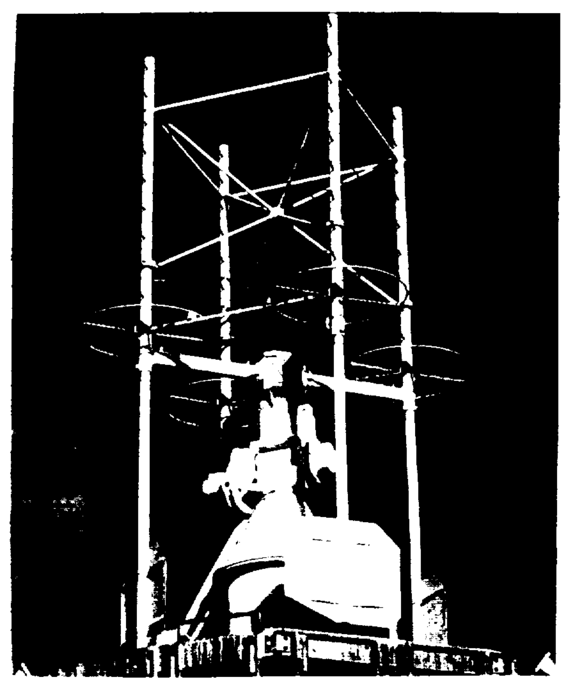


Figure 3-18. Retrofit AGAVE Antenna

The ship has a billboard antenna which consists of two broadband helixes for reception in the 225- to 260-MHz and 290- to 300-MHz bands. The latter band is provided as an emergency or backup (to the 5-1 voice/command antenna) spacecraft voice transmission and reception capability. This mount also contains the dipole array for reception at 136 MHz but does not have autotrack capability at any frequency. It can be manually steered or slaved to other on-board autotracking antennas.

The relatively broad beamwidth of the lower frequency antennas permits compartively easy acquisition of the spacecraft signal. Therefore, they are often used to provide pointing data to narrowbeam precision tracking systems to aid in their acquisition of the spacecraft. They also commonly provide pointing data to station nontracking antennas, particularly command antennas. In general, all antennas at a station are capable of providing and receiving pointing data from other antennas and many are capable of programmed operation, where the antenna is positioned by an APP which converts predicted orbital data to antenna positioning signals.

3.6.3 AMPLIFIERS, CONVERTERS, AND MULTICOUPLERS

Low-noise preamplifiers (preamps) or parametric amplifiers (paramps) and multicouplers are connected between the antennas and the receiving equipment. The amplifiers are generally mounted on the antenna mount (as near the feed as possible) to minimize system noise temperature. Frequency converters are combined with some of the amplifiers for use with multiple frequency capability antennas to convert the received frequency to a value suitable for use by the telemetry and autotrack receivers. Multicouplers are used throughout the network to provide isolation between preamps and receivers and also to permit the connection of several receivers to a single preamp. Table 3-6 presents some of the characteristics of the various amplifiers.

System noise temperatures for the higher frequency capability systems are listed in table 3-7. The USB antenna systems have several configurations resulting in a variety of noise temperatures. Maser preamplifiers at the 26-meter stations give a measured "quiet sky" system temperature of 65 degrees K or less, including 8 degrees assigned to the maser itself. Many of the 9-meter USB stations have cryogenic (cooled) paramps giving system temperatures of about 95 degrees K while the remaining stations with uncooled paramps have values of 170 degrees K. (Stations with uncooled paramps are CYI, BDA, MIL, and VAN.) The ERTS 9-meter USB systems at Goldstone and Greenbelt with special cooled paramps realize system noise temperatures of about 86 degrees K. The 26- and 12-meter multiband telemetry antennas have system noise temperatures of about 195 degrees K at S-band frequencies and approximately 500 degrees K at 400 MHz except that improved paramps on the 12-meter systems at Johannesburg and Santiago have lowered the 400-MHz system noise temperature to 275 degrees K. System noise temperatures for the lower frequency antennas are not listed because of the wide variations in antenna temperature experienced at these frequencies. Antenna gain and preamp characteristics are listed in tables 3-5 and 3-6. The 136-MHz preamp used with the multiband antennas and the SATAN array antennas have recently been replaced and the amplifier noise figure given in table 3-7 is for this newer amplifier. Also, a new uncooled 6-channel S-band Varactor paramp is currently being developed. It will have capabilities similar to the currently used USB system cooled amplifiers, and will eventually replace them (except ERTS cooled paramps).

3.6.4 TELEMETRY RECEIVERS AND DEMODULATORS

3.6.4.1 General. A number of telemetry receivers are in use in the STDN. The more common units are briefly described in the following paragraphs.

3.6.4.2 USB Receivers and Demodulators. The unified S-band receiver system and demodulation equipment normally associated with the USB system is discussed in para 3.3.2.3. As was noted in this section, the MFR receiver described in para 3.6.4.3 will be utilized eventually with the USB systems.

Table 3-6. Typical STDN Preamplifier and Parametric Amplifier Characteristics

Unit	Antenna System	Passband (MHz)	Gain (dB)	Noise Figure (dB)
Paramp	26m (85') Multiband	2200 to 2300	Note 1	1.3
Paramp[a]	26m (85') Multiband	1690 to 1710	Note 1	1.3
Paramp	26m (85') Multiband	400 to 406	Note 1	2.5
Preamp	26m (85') Multiband	136 to 138	Note 1	2.5
Paramp	12m (40') Multiband	2200 to 2300	Note 1	1.3
Paramp[a]	12m (40') Multiband	1690 to 1710	Note 1	1.3
Paramp	12m (40') Multiband	400 to 406	Note 1	Note 3
Preamp	12m (40') Multiband	136 to 138	Note 1	2.5
Preamp	SATAN	136 to 138	Note 1	2.5
Preamp	TELTRAC	225 to 260	25	1.7
Preamp	AGAVE	225 to 260	25	1.7
Maser	USB 26m (85')	2260 to 2290 (tunable)	45	0.11
Paramp (cooled)	USB 9m (30') and 26m (85')	2200 to 2300	40	0.44
Paramp (cooled) (ERTS)	USB 9m (30')	2200 to 2300	40	0.28
Paramp (uncooled)	USB 9m (30')	2200 to 2300	22	1.28
Paramp	9m (30') T/M (4-1)	2200 to 2300	25	2
Preamp	9m (30') T/M (4-1)	225 to 260	25	3.5
Preamp	Ship 4-2	130 to 140	25	3
Preamp	Ship 4-2	225 to 300	25	4.6
Paramp	USB 4.3m (14') (GRARR)	2200 to 2300	25-35	2

Note

1. Gain is set at 25 dB above the losses to the receiver.
2. The 1700-MHz band is instrumented only at Rosman and Alaska.
3. Noise figure is 2.5 dB, except at Santiago and Johannesburg where it is 0.7 dB.

Table 3-7. STDN Receiving System Noise Temperatures

Antenna System	Frequency (MHz)	Quiet Sky System Noise Temperature (deg K)
26 meter (85-ft) TLM (ORR, ROS, ULA)	400 1700 2250	440 to 600 175 to 200 175 to 200
12 meter (40-ft) TLM (AGO, BUR, ETC, QUI, TAN, ULA)	400 1700 2250	440 to 600 175 to 200 175 to 200
26 meter (85-ft) USB (GDS and MAD)	2250	65 max with maser 88 max with cooled paramp
9 meter (30-ft) USB (ACN, AGO, BDA, CRO, CYI, ETC, GWM, HAW, MIL, VAN)	2250	95 with cooled paramp 86 with ERTS cooled paramp 170 with uncooled paramp
ARIA 2 meter (7-ft)	1500 2250	1830 392

Note

1. Lower frequency noise temperatures are not given due to the wide variation in antenna noise temperature at low frequencies.

2. Noise temperature values not available for the 9-meter (30-ft) telemetry dish on the Vanguard and at Bermuda.

3.6.4.3 Multifunction Receivers. The MFR is a functionally modularized receiver currently deployed at some STDN stations primarily as the receiving system for the 26- and 12-meter multiband telemetry antenna systems and with the GRARR systems. It is used also with the 4.3-meter USB systems (former S-band GRARR). By late 1976, MFR's will be the prime receiving system in the STDN, being deployed with all major telemetry systems (including USB). The MFR performs telemetry demodulation and monopulse autotrack functions, and also receives and processes the signal used for Doppler ranging.

The basic MFR is a polarization diversity autotrack and telemetry receiver with a diversity sum channel and a pair of diversity autotrack channels, each of which processes the two orthogonal polarizations. The sum channel is used as a reference for the autotrack cross-correlation function and carrier phase-lock function, and also for telemetry demodulation, when its output is applied to the MFR demodulators. The error channels develop error signals for the X and Y antenna drive control. Included in the receiver will be carrier demodulators for signals that are amplitude- frequency-, or phase-modulated. The receiver includes such features as optimal ratio predetection combining, computer control, remote control, and fault isolation test points.

A block diagram of the MFR system is shown in figure 3-19. As depicted in the diagram, the MFR is preceded by an antenna mounted preamplified converter to accommodate input frequencies ranging from VHF to X-band. In this way, any input frequency is converted to the 400- to 500-MHz input range of the MFR. The receiver is tunable over the 100-MHz band in 10-kHz steps. The local oscillator uses a digital phase lock synthesizer of excellent phase spectral purity.

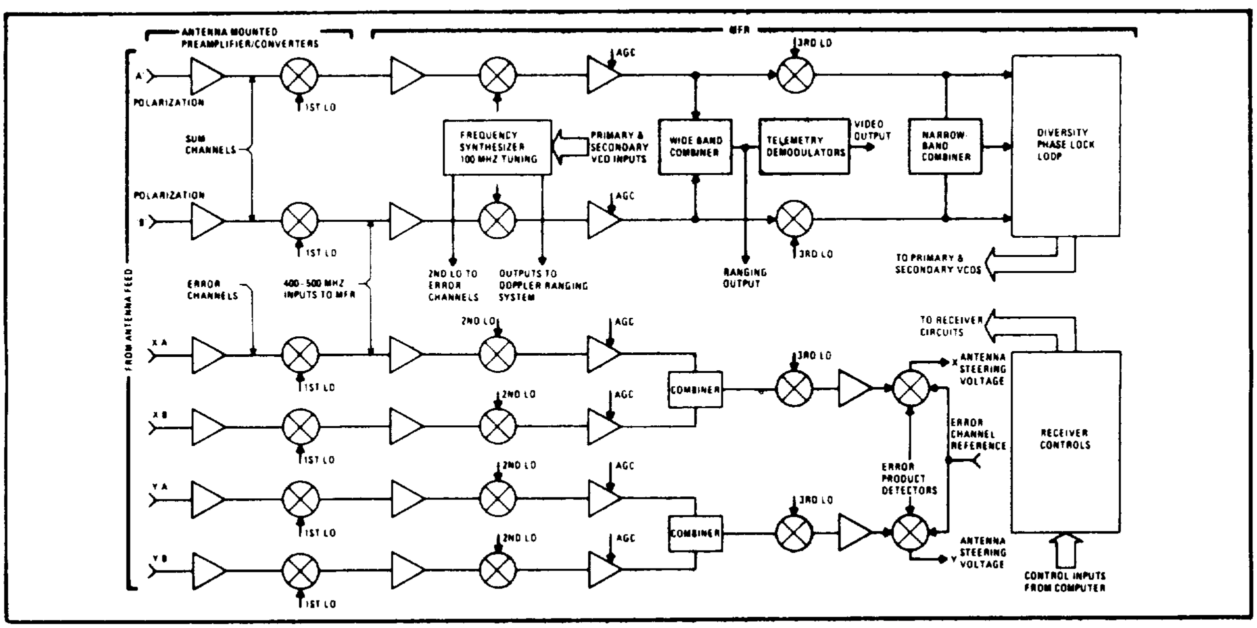


Figure 3-19. MFR Block Diagram

IF frequencies are 110 MHz and 10 MHz. The ranging output indicated is at 110 MHz. Narrowband telemetry demodulation capabilities with filter bandwidths from 10 kHz to 3.0 MHz, and wideband demodulators with filter bandwidths of 6, 10, and 20 MHz are provided. Video bandwidth is selectable from 1.5 kHz to 10.0 MHz. A summary tabulation of these and other major MFR characteristics is provided in table 3-8.

Table 3-8. MFR Characteristics

Parameter	Characteristics
Frequency	400 to 500 MHz.
Tuning	Synthesized 10-kHz steps plus continuous ±300 kHz for acquisition and Doppler tracking.
Tuning Modes	Carrier phase-lock (closed-loop) and AFC ON/OFF (open-loop) with cross-correlation for predetection combining.
Phase-lock Tracking Bandwidths	3rd order; 10 Hz, 30 Hz, 100 Hz, 300 Hz, 1000 Hz, 3000 Hz (one-sided)
Dynamic Range	Threshold to -25 dBm (120 dB maximum)
Demodulation	Open-loop (non coherent) AM, FM, PM. Closed-loop (coherent) AM, PM-linear and PM-sinusoidal.
Telemetry IF Bandwidths	Selectable; 10 kHz, 30 kHz, 60 kHz, 100 kHz, 150 kHz, 300 kHz, 600 kHz, 1 MHz, 1.5 MHz, 3 MHz, 6 MHz, 10 MHz, 20 MHz.
Video Bandwidths	Selectable, linear phase: 1.5 kHz, 5 kHz, 15 kHz, 30 kHz, 50 kHz, 75 kHz, 150 kHz, 300 kHz, 500 kHz, 750 kHz, 1.5 MHz, 3 MHz, 5 MHz, 10 MHz.
Autotrack Error Channel	Gain tracking: 2 dB. Phase tracking: 5 degrees typical. Modes: Phase-lock and cross-correlation.

When all MFR's are installed (late 1976), the 26- and 12-meter multiband antennas will each have four sum or data channels and three error channels, and the USB single band parabolic antennas will have four sum and two error channels. SATAN receive antennas will have two sum and one error channel. (One error channel provides drive signals to both antenna axes.) The sum channels will be switchable to all antennas at a station and to any frequency. The error channels will be dedicated to a given antenna, but will be switchable to any frequency associated with that antenna.

3.6.4.4 General Dynamics Diversity Receiver. This receiver is currently used primarily with the SATAN receiver system. It is tunable in 1-kHz steps between 130 and 140 MHz, and is capable of receiving other frequency bands through the use of appropriate downconverters. Intermediate frequency bandwidths are selectable from 10 kHz to 3 MHz. The receiver is capable of either FM or AM demodulation and features postdetection polarization diversity combining. In addition, a 3.25-MHz output off the second IF exists which can be connected to an external demodulator. The General Dynamics diversity receiver is not used for autotracking.

3.6.4.5 Other Receiving Equipment. Additional equipment in wide use in the network is summarized as follows:

a. Vitro R-1071A-1 Receiver. This receiver is provided at most USB equipped stations. With plug-in heads, it is tunable from 55 to 2300 MHz and has an IF bandwidth of 4 MHz.

b. Vitro R-2074A Dual-channel Receiver. This receiver is identical to the R-1071A-1 receiver, except the R-1071A-1 is a single-channel receiver. The R-2074A is a dual-channel version and is used for polarization diversity reception normally in association with the TELTRAC antennas and a Vitro DCA-5100A diversity combiner.

c. DEI TR-102 Single-channel Receiver. This receiver is tunable in discrete bands from 105 to 2300 MHz, has an IF bandwidth variable from 10 to 3300 kHz, is capable of receiving all Interrange Instrumentation Group (IRIG) signals, and features various plug-in capabilities. Diversity combination (postdetection) can be achieved through the use of two receivers and a TDC-1B diversity combiner.

d. DEI TR-109 Dual-channel Receiver. This receiver is used on the ARIA and can receive signals from VHF through S-band. Additional receivers used by the ARIA are designated MR-109. These are normally configured for diversity reception, two for VHF and two for S-band.

e. Microdyne 2200R Receiver. The Microdyne 2200R receiver is a dual-channel VHF receiver which accepts frequency- or phase-modulated carriers in the 105- to 420-MHz frequency range using plug-in demodulators and tuning heads. In combination with a matched diversity combiner, the system can provide combined predetection and postdetection outputs for recording or real-time processing. Both the receiver and the combiner can be monitored and controlled from a remote panel.

f. Teledyne 105A Autotrack Receiver. This receiver is currently used to provide monopulse tracking for the SATAN telemetry antennas. It is tunable from 130 to 140 MHz.

3.6.5 TELEMETRY DATA HANDLING EQUIPMENT

3.6.5.1 General. Receiver outputs are normally fed to decommutation systems, subcarrier discriminators, tape recorders, or some combination of this data handling equipment. Switching networks and/or patchboards are employed to provide flexibility in connecting the various receiver/demodulator outputs to any desired data handling equipment.

3.6.5.2 Decommutation Systems. Pulse Code Modulation (PCM) is the primary telemetry concept employed in STDN supported space projects and PCM decommutation systems are located throughout the network. Many stations including the Vanguard have Pulse Amplitude/Pulse Duration Modulation (PAM/PDM) decommutation capability. Pulse Frequency Modulation (PFM) detection and decommutation capability exist at a few stations.

PCM systems of several manufacturers (Radiation, Dynatronics, and Magnavox) are used in the network. All equipment includes the necessary signal conditioners and bit synchronizers and operates under the control of stored programs (Dynatronics and Radiation) or patchboards (Magnavox). In general, the units can handle PCM data coded Non Return to Zero (NRZ), Return to Zero (RZ), and Split Phase (BIØ) with data rate capabilities to 1 Mb/sec for NRZ formats and 500 kb/sec for RZ and split phase. The Magnavox equipment can handle data rates to only 200 kb/sec (all formats).

Newer decommutation equipment recently added to the network at most stations utilizes bit synchronizers permitting data rates up to 5 Mb/sec. Accepted codes with this equipment are NRZ-L, NRZ-S, NRZ-M, RZ, BIØ-L, BIØ-M, and BIØ-S. (Common PCM data codes are illustrated in figure 3-20.) This system utilizes stored program control.

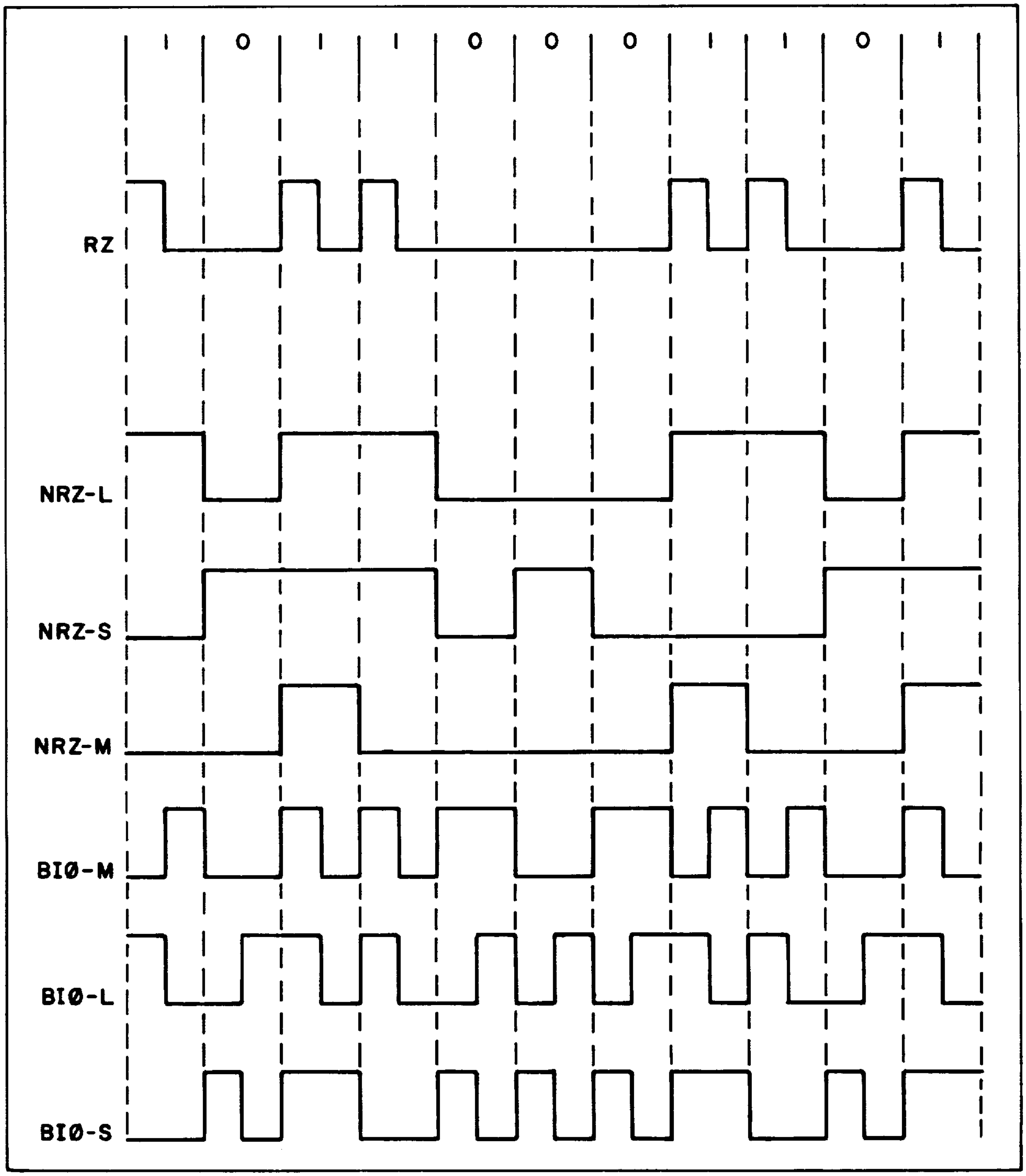


Figure 3-20. IRIG Standard PCM Data Codes

Stored program decommutators utilize magnetic core memories and can be programmed in any of three ways: by manual entry from the front panel, by paper tape reader, or by on-line computer. Output from the decommutators may be through Digital to Analog (D/A) provided channels or digital PCM suitable for further on-station processing, or transmission to GSFC. Displays vary for the different equipment, but include recorders for D/A channels, event recorders, printers, and front panel displays.

The PAM/PDM equipment located at many stations consists essentially of a Digital Data Formatter (DDF-13) which accepts serially formatted PAM or PDM data and converts it to a PCM NRZ-L 8-bit word format, including a 16-bit synchronization pattern for each frame of converted data. Data rate capability ranges from 1 b/sec to 10 kb/sec for 100-percent duty cycle PAM and 1 b/sec to 5 kb/sec for 50-percent duty cycle PAM or PDM. Parallel or serial output transfer is possible for use by either the on-station data processor or the PCM decommutator, respectively. PAM/PDM modulation techniques are generally not recommended for use, and without specific exception is not acceptable for use on NASA spacecraft.

PFM data handling equipment detects and decommutates PFM signals and produces data printout and display for monitoring spacecraft operations. A punch system generates a punched tape suitable for teletype transmission containing the data received so that the data may be transmitted to GSFC prior to further processing. (PFM data may also be transmitted in real time to GSFC prior to decommutation using NASCOM voice/data circuits. In this case, PFM frequency translation equipment is used to translate the signal to a favorable region of the voice/data transmission passband.) Only limited PFM capability is available in the STDN.

3.6.5.3 Discriminators, Demodulators, and Multiplexers. Most STDN stations have signal conversion equipment which include subcarrier discriminators with IRIG channel characteristics and subcarrier discriminators with variable center frequency and bandwidth characteristics for processing FM/FM multiplexed data channels.

In addition, the stations have equipment which permits the multiplexing of multiple channels of analog data through the use of subcarrier Voltage Control Oscillators (VCO) and of summing amplifiers. VCO's operate at standard IRIG frequencies and channel capacity is 18 (plus one external input, such as timing) subcarriers or 36 subcarriers, depending on the specific equipment. The multiplexed signal can be recorded as a composite on a single channel magnetic tape.

Tunable PSK demodulators at most stations are capable of accepting subcarrier frequencies in the range of 1 kHz to 2 MHz, and PCM/PSK bit rates from 1 b/sec to 1 Mb/sec. Efforts are currently under way to develop quadriphase demodulation equipment compatible with the MFR and capable of data rates to 30 Mb/sec.

3.6.5.4 Recorders. The STDN recorder subsystems include magnetic tape, strip-chart, and X-Y type recorders. Flexibility is provided through matrix switching and patching systems which interface the recorders with the various telemetry equipment discussed previously, including the PCM decommutators, demodulators, and multiplexers. Timing signals are available to the recorders for data correlation purposes.

Wideband magnetic tape recorders (Revere-Mincom M-22) provided at most stations have a response from 400 Hz to 1.5 MHz using direct recording and from dc to 500 kHz with FM recording, at a tape speed of 120 in./sec. Tape speeds from 3-3/4 to 120 in./sec are available with proportional response frequencies. These recorders have 14 tracks with capability combinations of up to 7 tracks using FM recording and direct recording on the remaining tracks. The ARIA wideband tape recorder is a Revere-Mincom 28/14 track recorder with two FM tracks. Tape speeds are 15, 30, 60, and 120 in./sec.

Many stations have Ampex FR-1900 recorder/reproducer units with direct record bandwidths to 2 MHz, in addition to the 1.5-MHz bandwidth recorders.

Former STADAN stations are generally equipped with seven-track 500-kHz bandwidth Ampex FR 600 recorders with tape speeds between 1-3/4 and 120 in./sec. Some new Bell and Howell VR 3400 intermediate bandwidth track recorders have been procured recently to replace and/or supplement the older FR 600 recorders.

Narrowband recorders are also in use. Typical frequency response is 0 Hz to 20 kHz and 300 Hz to 250 kHz direct record at 60 in./sec. The Revere-Mincom M-25 is typical of these recorders with 14 tracks and tape speeds from 7-1/2 to 60 in./sec.

Two types of television magnetic tape recorders, the Ampex VR 660-C and VR 1100 models, widely used in the network have the following characteristics:

a. Ampex Recorder VR 660-C. The VR 660-C is a magnetic tape recorder for recording television signals. The unit is portable with a video frequency response of ±3 dB, from 10 Hz to 4.2 MHz, and an audio response of ±3 dB from 50 Hz to 9 kHz. This recorder has the capacity of recording for 40 minutes with 6-1/2 inch tape reels, or of recording for 3 hours and 15 minutes with 10-1/2 inch tape reels.

b. Ampex VR 1100. The Ampex VR 1100 is a magnetic tape recorder for television signals. Tape speeds of 15 and 7-1/2 in./sec are available. The system uses 2-inch Mylar base tape and the record times for a 14-inch diameter tape reel are 96 minutes at 15 in./sec or 192 minutes at 7-1/2 in./sec. The monochrome frequency response is uniform within ±2 dB from 20 Hz to 4.0 MHz for 60 fields per second systems and 20 Hz to 5.0 MHz for 50 fields per second systems. Typical resolution performance exceeds 350 lines/field. The frequency response for the audio channel is ±2 dB from 50 Hz to 10 kHz at 15 in./sec tape speed and ±3 dB from 50 Hz to 6 kHz at the 7-1/2 in./sec tape speed. Other video recorders in limited use are the VR-1000, TR-70, and TR-5.

Several types of low-frequency voice magnetic tape recorders are located throughout the network as are various types of stripchart recorders including thermal writing and direct recording (galvanometer) machines. These instruments are used for on-station presentation of spacecraft data or for test and checkout purposes.

3.6.5.5 Data Transmission Subsystem. Some stations are equipped with Data Transmission Subsystems (DTS) which serve to interface the station data handling equipment with the communications modems. This equipment, consisting of both encoders and decoders (for transmission or reception at the station), provides for real-time transfer of digital data between GSFC and the individual stations.

Computerized stations utilize the computer in this link between the decommutator and the communications modem and it is expected that as the Digital Data Processing System (DDPS) (refer to para 3.8.3) concept is implemented the DTS equipment will be phased out.

3.7 COMMAND CAPABILITIES

3.7.1 GENERAL

The STDN command capability provides the means by which messages are transmitted to spacecraft. Types of messages include simple on/off commands, spacecraft control instructions, memory loads, and timing updates. Although individual STDN stations have capabilities for local generation and transmission of commands, they are normally originated at the spacecraft control center and transmitted via NASCOM lines to the desired STDN station for transmission to the spacecraft. Several basic command modes and transmission frequency bands are in use, and these are discussed in para 3.7.2. A brief description of the pertinent equipment is given in para 3.7.3.

Command standards are described in the Aerospace Data Systems Standards, available from the Aerospace Data Standards Office, Code 730.4.

3.7.2 COMMAND MODES AND FREQUENCIES

A Spacecraft Command Encoder (SCE) system has recently been installed at all prime STDN stations and is currently being used with some projects. This system will be an integral part of the "standardized" network (refer to para 1.3), and will have the capability of processing command formats previously used in both manned and unmanned flight programs. The basic command modes are tone, tone digital, PCM/FSK, and PCM/PSK.

A brief description of these modes as they have been used in the past is presented in para 3.7.2.1. The SCE system being software-controlled is not inherently restricted to the specific details in each of these modes. For example, in the tone mode, the SCE system is not limited to five tones, nor is it limited to the specific configuration discussed in the tone digital mode. In general, user command mode designs should be approved by GSFC prior to implementation.

3.7.2.1 Command Modes. The SCE equipment will accommodate all of the command modes described in para a through d and, since the system is software-controlled, considerable flexibility to vary individual format parameters exists. Technically, system flexibility is limited primarily by the finite core memory capacity (20-k word) and possibly by transmitter RF spectrum considerations. In practice, availability of software and programming resources will, at least initially, restrict flexibility.

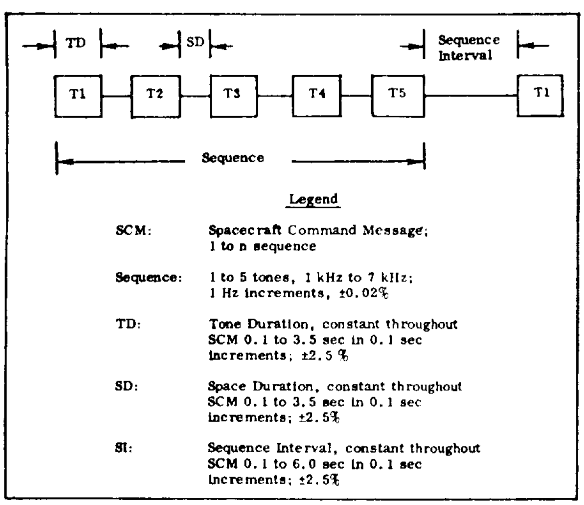


Figure 3-21. Tone Command Format

a. Tone Command Mode. The tone command mode is used where a few on/off type commands are required. The Radio Frequency (RF) carrier of the command transmitter is modulated with a series of discrete single audio tones. Sequential transmission is employed with an address tone normally sent first to "arm" the spacecraft decoder. The execute tones follow to accomplish the particular command functions and may consist of up to four additional tones in sequence. Tone frequencies available and other pertinent tone format data are shown in figure 3-21.

b. Tone Digital Command Mode. This mode was developed for spacecraft requiring 70 or less simple, real-time, on/off commands. It consists basically of a 4-state (sync, 1, 0, blank) signal, pulse duration modulated, with constant bit-ratio word coding and repetitive word formatting. A series of five words, each consisting of eight bits plus one synchronization and one blank period, are sent for each command. The series consists of a unique address word sent twice followed by an execute word sent three times. The address code consists of a combination of four 1's and four 0's. This is constant-bit ratio coding.

PDM of an audio subcarrier in the 7- to 16-kHz band is used for the bit coding. A bit period is 72 cycles of the subcarrier frequency. The sync bit duration is 54 cycles, the 1 bit is 36 cycles, and the 0 bit is 18 cycles of the subcarrier frequency. The subcarrier modulates the transmitter carrier or, alternatively, the command encoder may be operated to key the transmitter on during pulses and off between pulses. Figure 3-22 illustrates the tone digital command system word structure and frame format.

c. PCM/FSK Command Data System. This system is a high-capacity, binary, up-data link for transmitting commands or other data to spacecraft on RF command channels. The message configuration is similar to a computer instruction as partitioning can be used to designate various functions, such as addressing, event timing, error checking, and subsystem control. This type of command data can be for real-time execution or memory load for long term storage, or delayed execution.

Initial bit modulation is PCM-NRZ. This pulse code is frequency modulated (frequency shift key) into an intermediate passband by coherently switching a subcarrier oscillator between two assigned frequencies in the 7- to 16-kHz band. A sinusoidal bit synchronization signal (data rate clock) is Amplitude Modulated (AM) onto, or summed with, these data subcarriers, and the result modulated onto the uplink carrier. Figures 3-23 and 3-24 illustrate the resulting AM and summed signals, respectively.

The heirarchy of command data is the bit, frame, and message in that order. The bit is a binary digit, i.e., 1 or a 0. A frame is the smallest group of bits that makes up a single command transmission. As a typical example, a frame might contain a spacecraft address followed by a command, a command complement, a memory load instruction, or a time tag. The frame is divided into an uninterrupted sequence of bits.

For any given spacecraft the number of bits in each frame are the same. Two message formats are available: the command format and the memory load format; formats are illustrated in figure 3-25. In the command format, the maximum frame length is 64 bits, and any number of frames can be transmitted until the end of the message. Each frame contains a spacecraft address. In memory load format, a standard frame is followed by a number of bits, not to exceed 4096 bits. This number of bits will be some integral multiple of the number of bits (n) assigned to the frame. Not more than four different multiples (m) may be used by any given spacecraft. A message must be preceded by a number of 0's and a 1 for synchronization purposes. A break of subcarrier will occur after every message. (The SCE system maximum frame and message lengths are 128 bits and 65 k bits, respectively.)

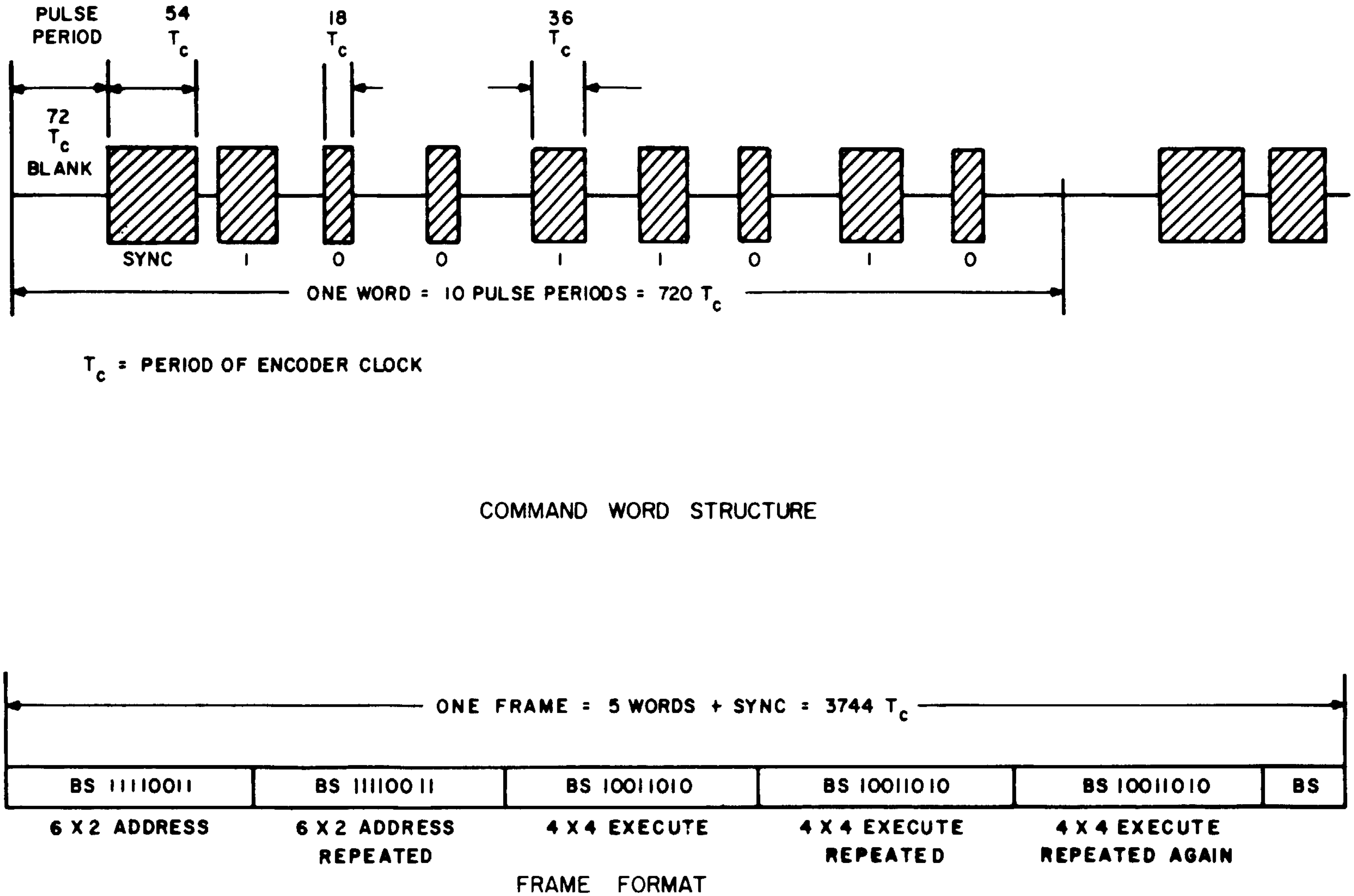


Figure 3-22. Tone Digital Command Word Structure and Format

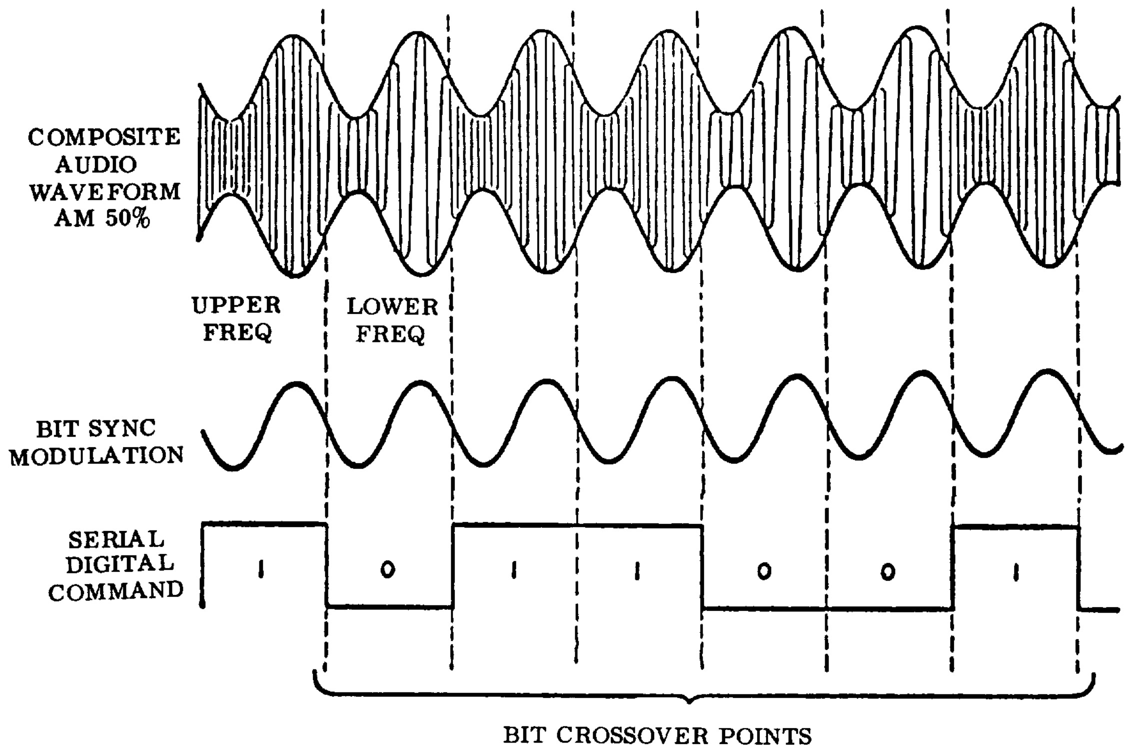


Figure 3-23. PCM/FSK-AM

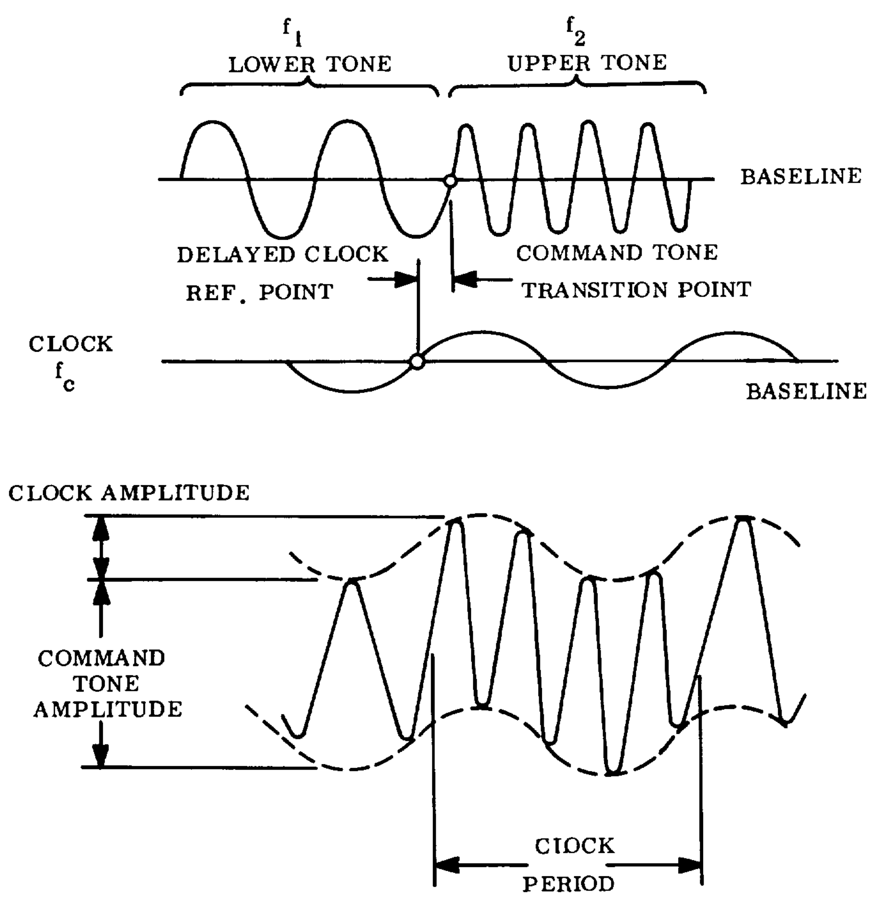
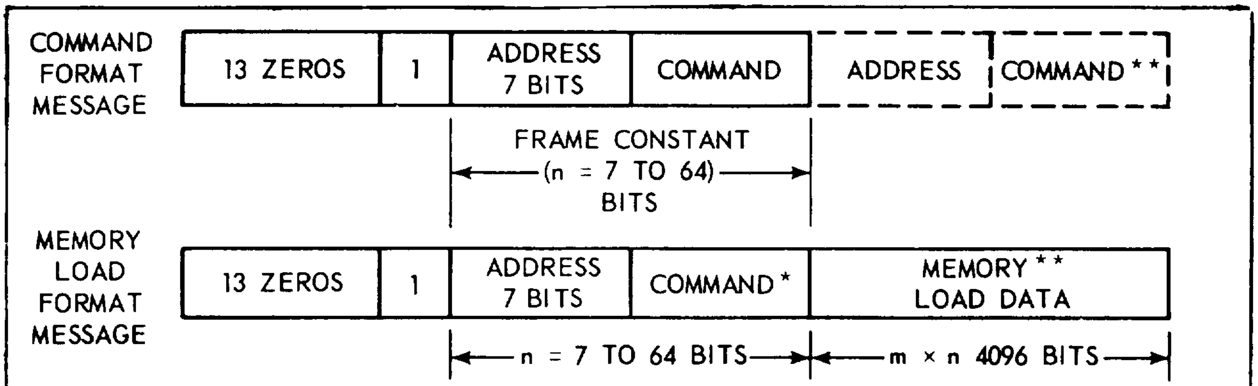


Figure 3-24. PCM/FSK Summed



n IS ASSIGNED A SINGLE VALUE FOR ANY GIVEN SPACECRAFT.

m IS AN INTEGER, AND IS ASSIGNED NOT MORE THAN FOUR VALUES FOR ANY GIVEN SPACECRAFT.

*MEMORY LOAD INSTRUCTION COMMAND; MUST BE A HAMMING DISTANCE OF AT LEAST 2 FROM ANY OTHER COMMAND.

**THERE WILL BE A BREAK OF SUBCARRIER BETWEEN MESSAGES.

Figure 3-25. Command Format and Memory Load Format

d. PCM/PSK Command System. This system has been used extensively for manned flight command support (Apollo and Skylab). It is currently being used to command the unmanned Earth Resources Technology Satellite (ERTS) and Explorer 51 satellite, and its use is planned on future spacecraft. Basically it is similar to the PCM/FSK system except that phase instead of frequency modulation is used.

With this system, the initial bit modulation may be NRZ or split phase. This digital data PSK modulates a low-frequency sinewave (subcarrier) which is added to a second phase coherent sinewave used for synchronization. This composite signal is then modulated on an uplink subcarrier or, alternatively, directly onto a carrier. The addition of the low-frequency modulation subcarrier and the clock (synchronization) signal may be linear summation as shown in figure 3-26 or, alternatively, amplitude modulation may be used (figure 3-27). The following paragraph describes this system as it was used for Apollo and Skylab (and planned for ASTP programs), and table 3-9 lists other characteristics and command modes.

In the Apollo and Skylab progams, commands were transmitted using either the USB system or a 450-MHz UHF command system. With either system, the command was processed by a 642B computer (refer to para 3.8) and fed to a command encoder (called the updata buffer) where the digital data was converted to PCM/PSK. The Updata Buffer (UDB) output was frequency modulated onto a 70-kHz subcarrier in the USB case and directly onto the 450-MHz carrier for the UHF system. The 70-kHz subcarrier was phase modulated onto the S-band uplink carrier.

The basic information bit rate was 200 b/sec; however, since 5-for-1 subbit encoding was employed for additional security, the computer output data rate was 1 kb/sec. A 2-kHz subcarrier was PSK modulated by this bit stream and the result linearly added to a 1-kHz synchronization signal. this composite then modulated the uplink carrier or subcarrier.

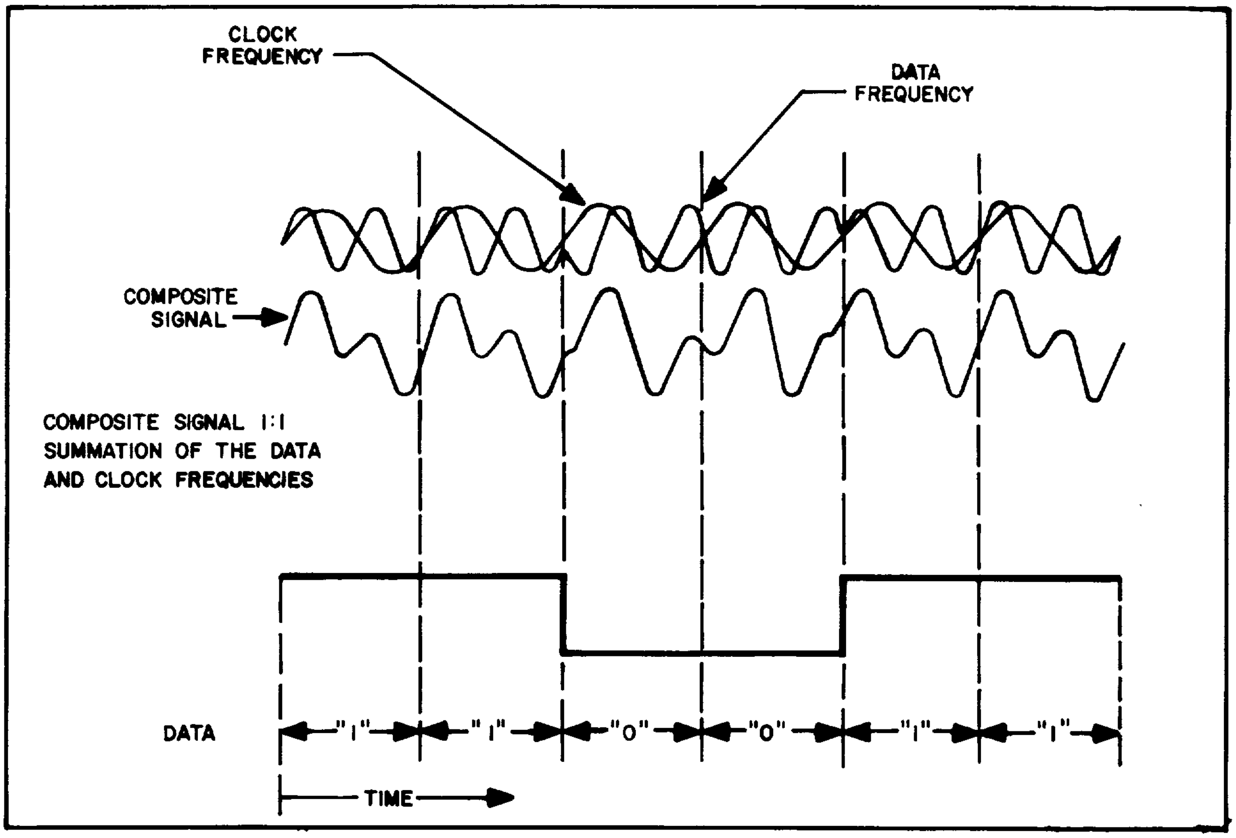


Figure 3-26. PCM/PSK Summed

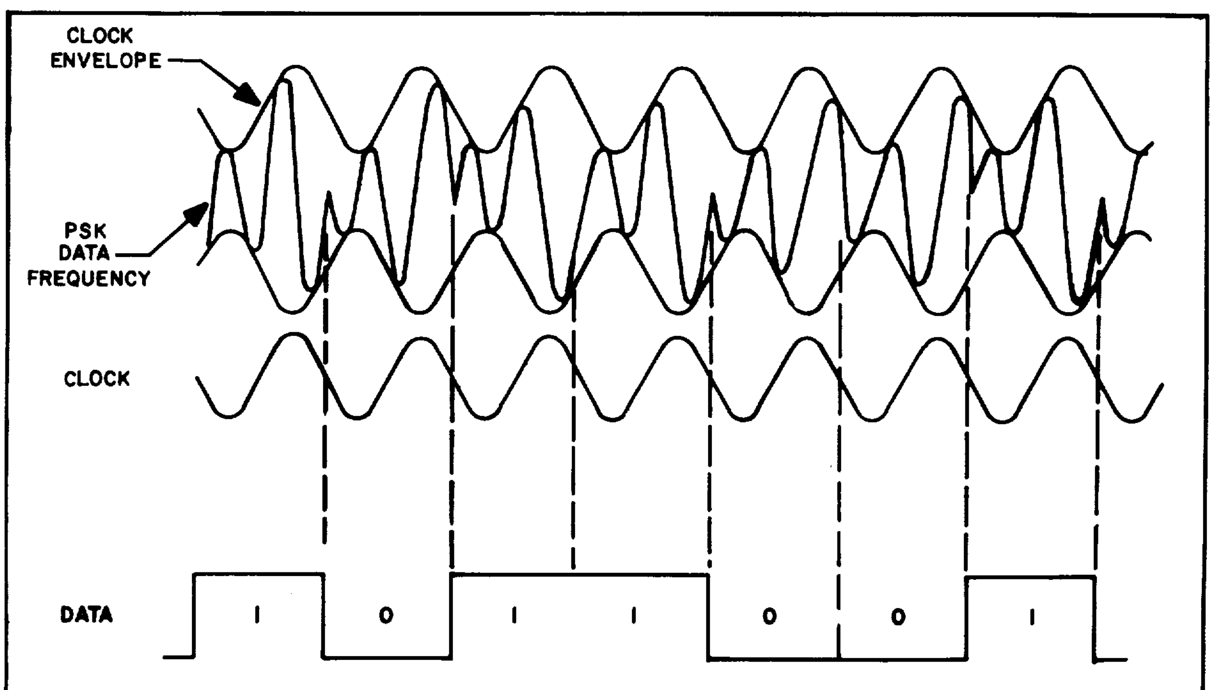


Figure 3-27. PCM/PSK AM Signal

Table 3-9. SCE Command Modes and Parameter Ranges

MODE	CLOCK FREQUENCY RANGE	TONE OR SUB-CARRIER FREQ RANGE	CLOCK TO SUBCARRIER FREQ RATIO	CLOCK TO SUBCARRIER PHASE (DEG)	CLOCK TO SUB-CARRIER RATIO OR MOD INDEX	TONE DURATION OR NO. OF CYCLES	KEYING MODES
TONE	NOT APPLICABLE	1 KHZ TO 7 KHZ IN 1 HZ INCREMENTS ACCURACY ±0.02%	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	TONE 1 TO 3.5 SEC SPACE 0 TO 3.5 SEC ΔT= 0.1 SEC. TOLER-ANCE ±1 MSEC. SEQ-UENCE INTERVAL 0 TO 6 SEC	NRZ TONE = 1 SPACE = 0
TONE DIGITAL	NOT APPLICABLE	7 KHZ TO 10 KHZ IN 1 HZ INCREMENTS, 10 KHZ TO 16 KHZ IN 2 HZ INCREMENTS, ACCURACY ±0.02%	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	SYNC: 54~ ONE: 36~ ZERO: 18~ BLANK: 72~	NRZ WITH SYNC
PCM/FSK A.M.	1 HZ TO 2 KHZ IN 1 HZ INCREMENTS ACCURACY ±0.02%	7 KHZ TO 10 KHZ IN 1 HZ INCREMENTS, 10 KHZ TO 16 KHZ IN 2 HZ INCREMENTS, ACCURACY ±0.02%	ANY FREQUENCY ASSIGNMENTS WITHIN THEIR RESPECTIVE RANGES	0 TO 360 IN 0.7 INCREMENTS TOLERANCE ±3	MOD INDEX: 0, 10, 20, 30, 40, 50, 60, 70, 80, AND 90% TOLERANCE ±5%	NOT APPLICABLE	NRZ
PCM/FSK SUMMED	1 HZ TO 2 KHZ IN 1 HZ INCREMENTS ACCURACY ±0.02%	7 KHZ TO 10 KHZ IN 1 HZ INCREMENTS, 10 KHZ TO 16 KHZ IN 2 HZ INCREMENTS ACCURACY ±0.02%	ANY FREQUENCY ASSIGNMENTS WITHIN THEIR RESPECTIVE RANGES	0 TO 360 IN 0.7 INCREMENTS TOLERANCE ±3	CLOCK TO SUB-CARRIER RATIO: 4:1, 3:1, 2:1, 1:1, 2, 3, 4, 5, 6, 7, 8, 9, 10 TOLERANCE ±5%	NOT APPLICABLE	NRZ
PCM/PSK A.M.	1 HZ TO 8 KHZ IN 1 HZ INCREMENTS ACCURACY ±0.02%	2 HZ TO 10 KHZ IN 1 HZ INCREMENTS, 10 KHZ TO 16 KHZ IN 2 HZ INCREMENTS, ACCURACY ±0.02%	1:N_R N_R = 2,3,4,...512 WITH THE RE-STRICTION, $F_{SUB} \leq$ 16 KHZ	0 TO 360 IN 0.7 INCREMENTS TOLERANCE ±3	MOD. INDEX: 0, 10, 20, 30, 40, 50, 60, 70, 80, AND 90% TOLERANCE ±5%	NOT APPLICABLE	NRZ OR SPLIT PHASE (N_R EVEN ONLY)
PCM/PSK SUMMED	1 HZ TO 8 KHZ IN 1 HZ INCREMENTS ACCURACY ±0.02%	2 KHZ TO 10 KHZ IN 1 HZ INCREMENTS, 10 KHZ TO 16 KHZ IN 2 HZ INCREMENTS, ACCURACY ±0.02%	1: N_R N_R = 2, 3,4,...512 WITH THE RE-STRICTION $F_{SUB} \leq$ 16 KHZ	0 TO 360 IN 0.7 INCREMENTS TOLERANCE ±3	CLOCK TO SUB-CARRIER RATIO: 4:1, 3:1, 2:1, 1:1, 2, 3, 4, 5, 6, 7, 8, 9, 10 TOLERANCE ±5%	NOT APPLICABLE	NRZ OR SPLIT PHASE (N_R EVEN ONLY)

Four different word lengths (12, 22, 30, or 35 bits) were used. Different lengths were used for different functions and systems. The first six bits were used for vehicle and system address, with the remaining bits comprising the basic command information.

e. Tone System Mode. A fifth command mode has been used on past manned flight programs in conjunction with the 450-MHz command system. This is a tone system which uses an audio frequency coder which is an integral part of the UHF command system. The coder is capable of generating discrete IRIG frequencies in the range of 7.5 to 73.95 kHz. Commands are encoded by associating the functions to be performed with combinations of the available oscillator frequencies. Combinations of two or three frequencies are normally employed in this system; e.g., the outputs of oscillator 1 and 6 might represent one function and the outputs of oscillators 2, 5, and 12 could represent another function. The output from the 20-oscillator channels are combined and fed to the transmitter for relay to the spacecraft. The SCE equipment recently installed in the network does not have this capability and its use should not be planned.

3.7.2.2 Command Frequencies. Nominal command carrier frequencies currently in use are 2090 to 2120 MHz, 406 to 549 MHz, and 147 to 155 MHz. Current plans are to expand the 2090- to 2120-MHz frequency capability to 2025 to 2120 MHz, and phase out use of the 450- and 150-MHz capabilities. It is expected the wider frequency band equipment installations will begin in early 1975 and be completed throughout the network in 1976. The 450-MHz command frequency usage will be discontinued following its use on the joint US/USSR mission currently scheduled for July 1975, and it is planned to terminate most use of the 150-MHz capability by January 1980. Only limited support with this frequency is planned after January 1978 and its use generally should not be planned following 1978.

Limited use of the 450-MHz frequency will be retained for range safety support at Bermuda as it is currently used. Command modulation is accomplished by special equipment (digital range safety equipment) provided for this function.

3.7.3 COMMAND EQUIPMENT

Command equipment can conveniently be divided into three categories: encoders, transmitters, and antennas.

3.7.3.1 Encoders. A number of encoders have been used, and are still being used in support of various spaceflight programs. Many of these encoders were limited to use on only one or two projects since they were built to specific requirements. The SCE system currently implemented at all standard STDN stations provides the capability to support a wide variety of requirements as it can accommodate each of the four basic command modes (tone, tone digital , PCM/FSK, and PCM/PSK) and, in addition, since it is a computer-controlled system, can accommodate many variations within these modes. This system is interfaced with both the S-band and VHF transmit capabilities. It is able to operate independently or in conjunction with other on-station computers, gaining additional communications control capability and flexibility when operating with other computers. The SCE accepts real-time command messages for immediate processing during an active pass or nonreal-time messages destined for future spacecraft passes. Nonreal-time messages are processed when nonpass-time is available, and are stored for use when needed. Command related data and instructions may be generated at a project control center and transmitted over NASCOM lines for SCE processing and transmission to the spacecraft,or the commands may be generated on station in accordance with control center instructions.

Command messages may be bit or mnemonic structured. The bit structured sequence is a message formatted bit by bit; all data bits to be transmitted to the spacecraft (except message synchronization bits) are contained in this message. The mnemonic structured command sequence is a message which provides the data required for the construction of the command. The SCE system then generates the command message in accordance with the input mnemonic sequence. Command data from the control center is transmitted in 1200-bit blocks at rates to 7.2 kb/sec.

Error protection codes such as subbit encoding, parity, polynomial, complements, etc., can be added to the data by the system software if desired. Reliability of the SCE transmissions is enhanced through a verification process wherein the transmitted signal is captured at the antenna, demodulated, and qualitatively examined for accuracy. Further assurance of correct commanding may be obtained by examining downlink telemetry, through an interface with the telemetry decommutator, and comparing with specified responses.

The SCE system achieves flexibility through use of a digital computer (H-316, refer to para 3.8.2) which may be programmed to accommodate a wide variety of formats by varying individual programmable parameters. These parameters are clock frequency, data frequency, clock-to-subcarrier frequency ratio, clock-to-subcarrier phase ratio, modulation index, message length, bits per frame, tone/space duration, and sequence interval. Table 3-9 indicates the ranges of some of these parameters along with other pertinent SCE data and tolerances.

In normal operation, program information for a specific spacecraft project is located on a cassette tape reserved for that project. This may be read onto a 4-million bit disc memory system where it is stored along with data for other spacecraft. When needed, the data is transferred to the SCE 20 k word core memory for processing and subsequent transmission to the spacecraft. The SCE system, in addition to its prime function of generating and transmitting spacecraft commands, generates control messages for local printout and/or transmission back to the control center. An example of this type message is the pass summary message, which summarizes the command actions for a particular pass.

The SCE system will eventually replace most of the encoders which are currently in use. One of the current systems widely used is the Consolidated Systems Corporation (CSC) encoder which is capable of generating both tone and tone digital commands. A second example is an encoder used for OGO and other satellite projects which generates both tone and PCM/FSK commands. An updata buffer is still being used for manned flight support; this unit accepts digital data from an on-station computer and converts it to the PCM/PSK format as described earlier for the Apollo program.

3.7.3.2 Station Command Transmitters. A brief description of the UHF and VHF command transmitters currently in use in the STDN is given below. The USB system also used for command is described in para 3.2.

UHF command systems are capable of 10-kW output power through the use of 80-watt (maximum) FM exciters (Model 6031) driving Model 240-D-2 power amplifiers, which can be bypassed in event of a failure. These solid-state exciters are tunable over a range from 410 to 460 MHz. The Vanguard uses equipment of different manufacture but with similar characteristics (UD-10 exciter transmitter and UD-20 power amplifier).

VHF transmitters capable of AM, FM, or PM operation are widely used for VHF command. They are tunable from 147 to 155 MHz and have a maximum drive power of 250 watts in the AM mode and 500 watts in the FM or PM modes; when operated in conjunction with linear amplifiers, the output power is increased to 2.5 kW (AM) and 5 kW (FM/PM). Some older AM transmitters also remain in limited service. Power output is 2.5 or 5 kW depending on the unit.

3.7.3.3 Command Antennas. Table 3-10 tabulates the types of antennas used for command in the STDN, and gives some of the characteristics.

Table 3-10. STDN Command Antenna Summary

Antenna	Frequency Band (MHz)	Gain (dB)	Beamwidth (deg)	Polarization
USB 26m (85')	2090 to 2120	51	0.3	RCP or LCP
USB 9m (30')	2090 to 2120	43	1	RCP or LCP
USB 4.3m (14')*	2090 to 2120	36	2.1	RCP or LCP
Quadhelix	405 to 450	18	20	LCP
Vanguard (5-1) (Dual Quadhelix)	406 to 500	18	20	LCP, RCP
SATAN	120 to 155	20	13	RCP, LCP linear orthogonal
SCAMP	147 to 155	17	13	RCP, LCP linear orthogonal
Disc on Rod	122 to 155	12	40	RCP, LCP linear orthogonal
Dual Yagi	148	13.5	38	RCP, LCP linear orthogonal

*Formerly GRARR antennas.

The quadhelix antenna used for UHF commanding has a gain of 18 dB and beamwidth of about 20 degrees. Several antennas are used for commanding in the 150-MHz region. Dual-Yagi and SATAN command antennas are equipped with separate, steerable mounts which are controlled from the station command operations area. The gain of these antennas is approximately 13 and 20 dB, respectively. A single disc-on-rod antenna (12 dB gain) is mounted on the periphery of the Rosman (see figure 3-13) and Fairbanks 26m (85-ft) antennas. A new VHF command antenna, the Satellite Command Antenna on Medium Pedestal (SCAMP), has recently been installed at some STDN stations. This antenna is similar to the SATAN command array and has a minimum gain of about 17 dB. Polarization capabilities of all these antennas are right-hand circular, left-hand circular, and two linear orthogonal polarizations. Figure 3-28 shows the SATAN command antenna.

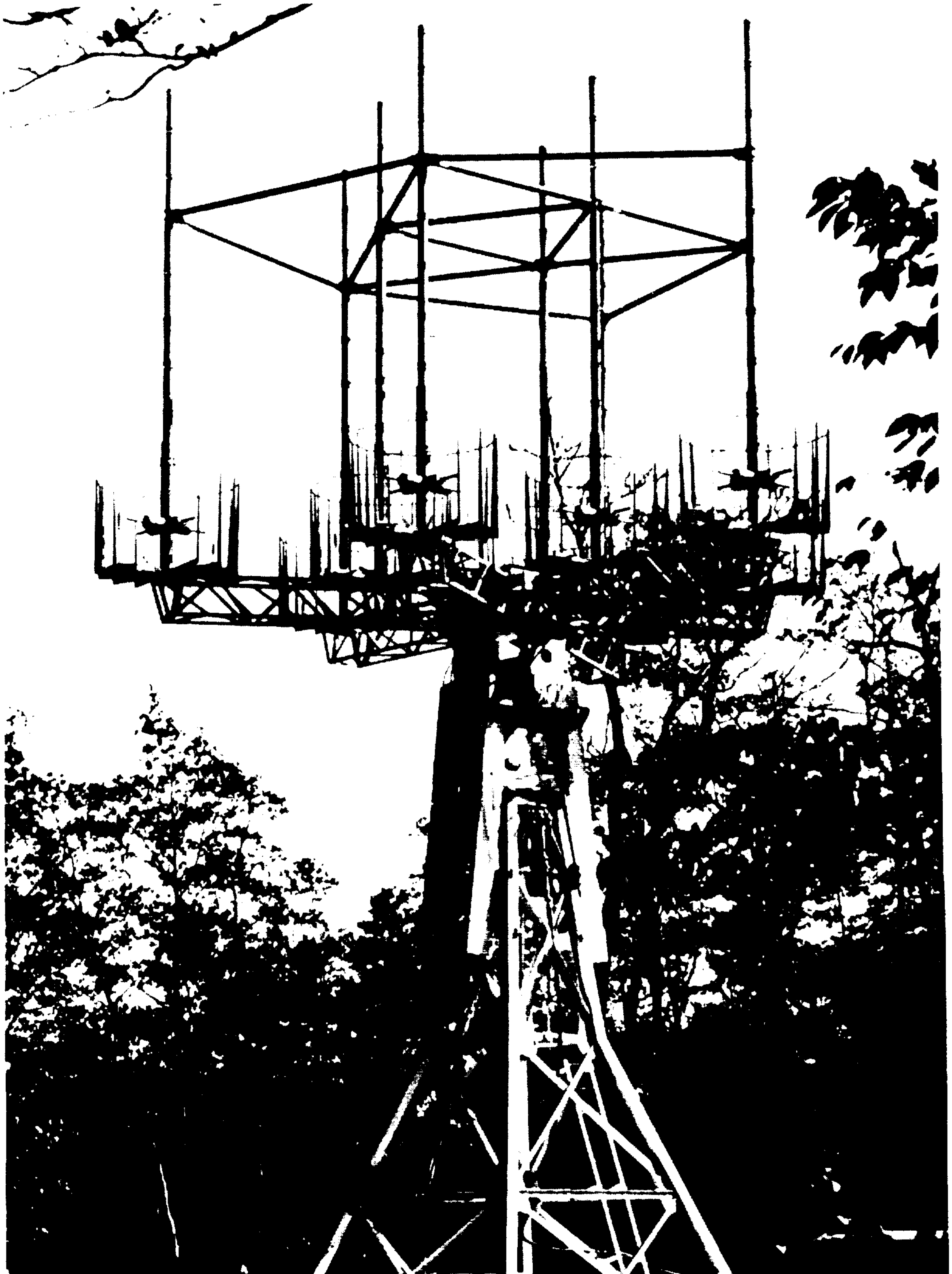


Figure 3-28. SATAN Command Antenna

3.8 REMOTE SITE COMPUTERS

Computers are used at the STDN stations for processing spacecraft-related data and for control and assistance in operating station equipment. Univac 642B computers are used extensively for processing telemetry and command data in support of manned spaceflight. The 642B is also being used in support of unmanned programs (e.g., ERTS and Explorer 51) and its continued use for future manned and unmanned programs is planned. Honeywell H-316 computers have recently been installed at all STDN stations as part of the Spacecraft Command Encoder (SCE) system (refer to para 3.7). Univac 1218 computers are, or soon will be, located at every STDN station except WNK. This computer is used primarily for processing acquisition data for 26-, 12-, and 9-meter parabolic antennas. Model 4101 computers are used with the C-band radar for acquisition and tracking data processing at Bermuda and Tananarive. A number of other computers are in limited use in the network including a PDP-9 (ULA), PDP-11 (ETC and ROS), DDP-516 (AGO, ETC, QUI), DDP-116 (ULA), SDS-910 (AVE and ROS), and a Univac 1230 (VAN). PB-250 computers formerly used primarily to prepare acquisition data for use with the 12- and 26-meter multiband telemetry systems and the AD/ECS-37A computers are no longer used. Additional PDP-11 computers and peripheral equipment are scheduled for distribution to the network in the 1975-1976 time frame. This equipment will be used in conjunction with the 642B's which will be redistributed in connection with the Digital Data Processing System (DDPS) implementation.

3.8.1 COMPUTER EQUIPMENT DESCRIPTION

Brief descriptions of the more widely used computer systems are given in para 3.8.1.1 through 3.8.1.3. This is followed by a discussion of types of computations for which they are used.

3.8.1.1 642B Computers. Generally, each USB equipped station has two identical modified Univac 642B medium scale computers. Associated with these computers at most stations is an Expanded Memory Unit (EMU) which contains two memory systems, one associated with each computer. The Merritt Island station has four 642B's including two associated with a second USB system. (The second USB systems at Goldstone and Greenbelt [ETC] each have one 642B.) The portable station at Newfoundland has two 642B computers and one 642B has been installed at Fairbanks for ERTS support. Single 642B computers have been installed recently at Santiago and Tananarive.

The two 642B computer systems (where there are two) are capable of intercommunication via an intercomputer channel, allowing operation as an integral unit. Normally one computer is designated as a command processor and the second as a telemetry processor. The equipment configuration and software programming is arranged so that if one computer fails the other can be switched to perform the major mission functions of the failed computer. The EMU serves to double the memory capacity of each computer from 32,768 to 65,536 thirty-bit words and increases the number of input/output channels from 16 to 20. Other characteristics of the computer are a 2.0 μsec read-write cycle time, a magnetic core memory capable of being randomly accessed, and an overlap memory capability which can increase the execution speed of various programs.

The Vanguard has two 642B computers, which are equipped and operated as command and telemetry computers. A third similar computer (Univac 1230) is associated with the Central Data Processing (CDP) system. This computer, in conjunction with peripheral equipment and buffers, interfaces with the other major shipboard systems, including navigation, tracking, timing, ship flexure, control, and communications. The system accepts data from various sources and presents outputs to other instrumentation systems for acquisition and tracking control, numerical display, plot board display, magnetic and paper tape recording, data printout, and data transmission either by teletype (TTY) or by high-speed data links. The CDP computer utilizes floating-point software and does not have an expanded memory unit.

The following peripheral equipment, in addition to the EMU, is used with the 642B computers:

a. The Univac 1540 Magnetic Tape Units (MTU's) contain four transports each and are accessible from either computer. The MTU's are capable of reading and writing with densities of 200, 556, or 800 frames per inch, at a speed of 120 in./sec, and will rewind at 240 in./sec.

b. The Peripheral Communication System (PCS) contains Data Transmission Units (DTU's) and a Model 1000 Interface System Adapter (ISA). The DTU's are used by the computers to transmit and receive high-speed data. The ISA contains a Greenwich Mean Time (GMT) buffer, which transfers parallel GMT data from the station timing standard to the computers, and a Computer Address Matrix (CAM) multiplexer, which provides a means of communication between the CAM keyboards and the computers.

c. The 1299 interconnection panel is equipped with multipole, double-throw switches for connecting and disconnecting the peripheral equipment to and from the computers, providing system flexibility.

d. The Univac 1232 Input/Output (I/O) console contains a paper tape reader, punch keyboard, and printer. It is used by the computer operator to load and control programs and to monitor computer operations.

e. The Motorola TP-4000 printer interfaces with the printer systems adapter (1222), which serves as an interface between the computer and the high-speed printers located at the Integrated Operations Control Console (IOCC) and in the computer area.

f. The Updata Buffer (UDB) is the interface between the command computer and the RF transmission equipment and serves to transform PCM/PSK digital command data to a form suitable for modulating the command transmitters. (Refer to para 3.7.)

g. The 1259 teletype unit consists of a standard AN/UGC-13 teletypewriter with an adapter to interface with the computer. It acts as an input/output device for the computer. The TTY is a Model 28 Automatic Send/Receive (ASR) unit which offers an automatic means of transmitting data between two points using either a land or radio link. The TTY may be operated with mechanical changes at speeds of 60, 75, 100, or 200 words per minute.

3.8.1.2 H-316 Computer. This computer is used with the Spacecraft Command Encoder (SCE) system for on-station command data processing as discussed in para 3.7. Associated with the computer are a central processing unit, 20-k word core memory, instruction set, and I/O channels for connection to the necessary peripheral devices. Programs may be stored on an associated 4-million bit disc memory. The computer is a general purpose, single address, 2's complement, parallel organized machine.

3.8.1.3 1218 Computer. This computer has associated with it a 1232 I/O console and 1259 teletype adapter with a modified ASR-28 TTY. The 1218 has a memory of 16,384 eighteen-bit words (expandable to 32,768) and eight I/O channels. The 1218 computer is electrically interfaced with the USB Antenna Position Programmer (APP) so that it can process acquisition messages into pointing data to drive the USB antenna.

(This function is accomplished by the CDP on the Vanguard.) The 1259 teletype adapter and the modified ASR-28 TTY interface the 1218 computer with off-station communications circuits. This computer is also used to generate drive tapes for positioning 26- and 12-meter telemetry antennas, but currently does not interface directly with these antennas. Provision exists for operating in this manner also with the USB antennas (i.e., generate drive tapes in lieu of direct interface). A 1218 computer is also used for processing C-band radar acquisition and tracking data at Hawaii. A 1218 is used for range safety impact prediction at Bermuda.

3.8.2 REMOTE SITE DATA HANDLING

The Univac 642B computers represent a significant capability which has been extensively used in the past for command and telemetry data processing in connection with manned flight programs. They have been and are being used also for support of unmanned programs. They will be used with the ASTP scheduled for July 1975, to provide support similar to that of past manned flights.

These computers are currently being reconfigured and reprogrammed to provide a greater capability for simultaneous multiple satellite data handling at each STDN station. When reconfiguration is complete, these computers and associated peripherals will provide the primary means of formatting and transmission of telemetry data from the stations to the appropriate data processing and control centers. The system will also be used to receive and manipulate command data in conjunction with SCE H-316 computers. Current plans are that tracking data will not be processed by this system, as this function will be handled by the tracking data processor (see para 3.2). This new computer operating concept or system, called the Digital Data Processing System (DDPS) is described in more detail in para 3.8.3. A brief description of current data handling by the 642B and other widely used computers is presented in para 3.8.2.1 through 3.8.2.3.

3.8.2.1 <u>Telemetry Data Handling.</u> Telemetry processing basically involves adapting the telemetered data stream to fit the off-station communication lines. Some of the techniques employed are as follows:

a. Format selection is a process whereby various formats are planned in advance of the mission, with each format containing only those parameters most pertinent to a particular phase of the mission. The desired format is then selected at the proper time in the mission sequence.

b. A similar process, parameter selection, involves selecting (out of the telemetry data stream) only those parameters desired to be transmitted in real time. The remaining data can be recorded and mailed back or alternatively transmitted in near real time postpass.

c. Rate reduction and truncation schemes have also been used; however, some loss of data results when using these techniques. Rate reduction involves transmission of a reduced number of samples (e.g., transmitting only every tenth sample of a particular word, thereby reducing the rate by a factor of 10) of a particular parameter, and truncation involves a reduced number of bits (e.g., transmit the 8 most significant bits of a 10-bit word). These techniques are applicable where the resultant deterioration in the parameter measurement would not be inconsistent with the planned use of the data. Again, the original bit stream can be recorded and transmitted postpass for more detailed analysis.

d. Data compression has been used successfully with the Skylab program telemetry data, with compression ratios on the order of 20 to 1 being achieved. Data compression involves basically the removal of most of the redundancy in the data stream so that only a minimum number of bits are required to send the information over the data line. It is planned to use data compression onthe ASTP mission.

It is important to recognize that, while various techniques have been employed in the past, emphasis with the DDPS system will be more on data handling and formatting than processing. This is consistent with the goal of eventually transmitting all satellite data from the stations electronically in real or near real time, thus precluding the use of magnetic tapes for this purpose.

3.8.2.2 Command Data Processing. The 642B computers have been used for sophisticated command data processing (formatting, encoding, storage, verification, dialogue with control center) in the past and this processing system will be used with the ASTP mission. In the future, the H-316 computer associated with the SCE will perform many of these functions and the DDPS system will operate with this computer to provide increased command capability. A further discussion of command capabilities is given in para 3.7.

3.8.2.3 Acquisition Data Processing. Univac 1218 computers are used at the stations primarily for the purpose of developing detailed antenna pointing data from designation data received at the station. Designation data is transmitted to the station as Inter-range Vector (IRV), Inter-network Predicts (INP's), or NORAD elements. A 29-point acquisition message, which has also been used, is being phased out. The computer is directly interfaced with the USB system APP so that real-time operations are possible. The 1218 also is used with the 12- and 26-meter multiband telemetry antennas; however, in this case, drive tapes are prepared off line and subsequently fed to the APP. This mode may also be used with the USB antennas. A 1218 computer is used also to drive the Hawaii FPS-16 C-band radar antenna (Model 4101 computers are used for this function with the C-band radars at Bermuda and Tananarive).

3.8.3 DIGITAL DATA PROCESSING SYSTEM

The DDPS concept has replaced the Station Data Acquisition and Control (STADAC) system concept described in the previous issue of this document. It is planned to implement the DDPS system at all STDN stations that are being retained as part of the standardized or integrated network. (These stations are listed in table 1-2. All stations, except those indicated to be closed, are scheduled to receive the DDPS except possibly Winkfield.) The system will consist of general purpose computers configured with uniquely designed interface hardware, peripheral equipment, and software, and will accommodate projected on-station data handling functions through 1980. Implementation will be in two phases. The first phase (phase I) will be effective at all stations (with the possible exception of Winkfield) and will consist essentially of a reconfiguration and reprogramming of existing Univac 642B data processing systems to a general purpose configuration. It is expected that this phase will be completed and be operational by mid 1975. The second phase (phase II) will include additional equipment and will be implemented only at selected stations. This phase will add to the operability, reliability, and capacity (increased telemetry bit rates and number of bit streams) of these stations. Implementation of this phase is scheduled for completion by late 1976. (Current plans are that phase II will be implemented at ACN, AGO, ETC, GDS, GWM, HAW, ORR, QUI, ROS, TAN, ULA, and possibly MIL.)

The DDPS will perform the following generalized functions: (1) real-time and near real-time formatting, control, and transmission of telemetry data to the appropriate project operation control centers, to the Information Processing Division (at GSFC) and other data users, and control and accountability of this data; (2) real-time command and control functions from the cognizant control centers, including real-time data manipulation (in conjunction with the SCE computer); and (3) transmission and verification of spacecraft computer and command memory loads. The system will become the primary means of formatting all remote station telemetry data for transmission to the appropriate user facility.

Phase I stations will utilize the existing STDN 642B systems as modified during phase I to accomplish telemetry, command, communications, and limited data base file functions. These systems will be reconfigured with both specialized input/interface hardware and operational software to ensure compatibility with standardized DDPS and NASCOM data handling and transmission criteria.

The remaining stations will receive a phase II system which includes (in addition to phase I) the following: a Display Processor (DP), a Telemetry Processor (TP), a File Processor (FP), and a Back-up Processor (BP).

The DP subsystems, utilizing a PDP-11 computer and Hazeltine Cathode Ray Tube (CRT) displays, will be incorporated to provide operator aided monitoring, control, and verification of station system/equipment, and data quality. The TP is primarily devoted to telemetry data collection, formatting, and buffering functions. The FP subsystem maintains the data base files, schedules required by DDPS, and also controls a Random Access Memory (RAM) and digital Magnetic Tape Units (MTU's) used for storage.

The TP and FP share a common PDP-11 BP computer. Two 642B systems are configured as an Executive/Communications computer subsystem (prime and back-up) which functions to maintain executive program control of the DDPS and as a communications processor/message handling subsystem. The DP (PDP-11, CRT displays, and associated interface and control hardware) supplements the phase I configuration to aid with the more complex control and monitor requirements of the multilink station.

3.9 NATIONAL AERONAUTICS AND SPACE ADMINISTRATION COMMUNICATIONS NETWORK

The National Aeronautics and Space Administration Communications Network (NASCOM) is a global system established and operated by NASA to provide long-line operational communications support of all NASA projects. NASCOM provides voice, data, and teletype communications between all ground tracking and data acquisition stations and the appropriate operations and control centers. It also provides for television and other wideband transmissions from selected stations. The network includes land lines, submarine cables, microwave and satellite links, and necessary terminal and switching facilities. In general, geographically diverse routes have been established from each station where possible so that no total communications loss will occur if the primary route fails.

3.9.1 VOICE/DATA CIRCUITS

NASCOM provides a system of full period leased voice circuits (nominal 3-kHz bandwidth) to virtually all stations and terminal points in the NASCOM network. Essentially all voice/data circuits are routed either directly to the GSFC Switching, Conferencing, and Monitoring Arrangement (SCAMA) or through various overseas NASCOM switching centers where conferencing, monitoring, and test facilities are available. The voice links interface with Air-to-ground (A-G) voice equipment at manned flight support stations to support spacecraft voice communications in addition to the general mission support services.

In general, the voice/data circuits are conditioned and tariffed so they may be easily switched to provide either voice or data communications.

High-speed data modem (modulator-demodulator) sets are provided at all STDN and DSN stations. Modems at STDN stations operate at 7200 b/sec for transmission of telemetry data, and operate at 2400 b/sec (different modems) for transmission of high-speed tracking data. Channels to the DSN stations operate at 4800 b/sec. Analog data may also be transmitted over the 3-kHz voice/data lines either directly or using multiplex equipment described in the section on telemetry. It should be noted that teletype transmission of tracking data (1 sample per 6 seconds) is adequate for most applications and consideration is being given to removal of the 2.4-k bit HSD modems from most STDN stations. (The modems will be retained at Bermuda, Merritt Island, and Vanguard for tracking data transmission during launch.)

3.9.2 WIDEBAND SYSTEMS

Wideband communication links currently exist between GSFC and several STDN stations, and between GSFC and JSC. Group bandwidth (48 kHz) channels connect GSFC with Fairbanks, Madrid, Orroral, and with the MCC at JSC. Rosman is connected to GSFC by a wideband link with 1.5 MHz total available bandwidth (not continuous) in addition to a two-way 20-kHz wideband channel.

Generally, these circuits are capable of operating in a variety of modes to accommodate varying requirements. Typically a 48-kHz circuit can carry 28.5 kb/sec of data along with four voice bandwidth channels, or as with the three 48-kHz circuits to JSC, 50 kb/sec of data. Wideband facilities are often specifically engineered by the carrier for the particular type of data to be transmitted and for interface with unique station equipment. Generally, a lead time of 24 months is required for implementation of such systems. TV channels for transmission of manned flight telecasts are leased as required for transmitting video from the STDN stations to MCC-JSC or to local facilities for formatting and broadcast to the public. It is planned to add additional wideband circuits to the various STDN stations, consistent with developing data transmission requirements and economic tradeoffs between wideband circuits and multiple voice data circuits. A development which may considerably enhance the feasibility of international wideband data communications in the future is the recent implementation by the Intelsat Consortium of a new flexible multiple access system in the Atlantic area. The system is termed Single channel per carrier Pulse code modulation multiple Access Demand assignment Equipment (SPADE). This system uses a 64-kb/sec PCM digital system as the basic unit for deriving a voice-quality channel; a fallout is the inherent capability of developing a 48- to 56-kb/sec digital data channel on the facilities of a single voice-equivalent channel (and possible multiples thereof). A NASCOM 50-kb/sec service using single channel-per-carrier facilities on the "space segment" between GSFC and Madrid has recently been established and is being cost effectively used in the network.

3.9.3 TELETYPE SYSTEMS

The NASCOM provides switched teletypewriter communications between all STDN stations and the various project computation and control centers. Generally, these are full-duplex (two-way simultaneous) circuits, leased on a full period basis which route information directly, or via the switching centers, to and from the stations, although some circuits are arranged for simplex (one-way) mode of operation. Circuit operation speeds are 100 w/min (75 baud) on domestic circuits, and a mixture of 66 w/min (50 baud) and 100 w/min on overseas circuits. Speed changes are provided by the overseas communications carriers at the gateway points. It is anticipated that eventually all TTY channels will be standardized at 100 w/min operation.

All traffic on the NASCOM teletype network uses a standard Baudot code (five information bits plus start and stop bits, per character) which includes encoded data for data processing machine use as well as for teleprinter applications. It is anticipated that at such time in the future as users of the network and the domestic and/or overseas carriers may adopt the 8-level American Standard Code for Information Interchange (ASCII), the NASCOM network will also convert to this system. Current practice is to specify new equipment procurements to be compatible with or easily convertible to this system. Current plans are that the new tracking data processing system (refer to para 3.2.2.3) being developed will use ASCII.

3.9.4 DATA FORMATS

Generally, network users are required to specify a high-speed data format compatible with existing STDN and NASCOM equipment. Figure 3-29 shows the basic NASCOM high-speed data format which must be used if automatic message switching or data quality monitoring by NASCOM is desired. The length of the data block may be any multiple of 12 bits; however, use of a 1200-bit block is encouraged in order to be compatible with planned future STDN data handling systems (refer to para 3.8). Content of the 1200-bit block is currently being defined for different message functions. It is expected that a 48-bit message header will immediately follow the first 48-bit routing or NASCOM header indicated in figure 3-29. It is expected that the last 24 bits will include a 22-bit algebraic (polynomial) code and 2 bits for use in flagging detected errors.

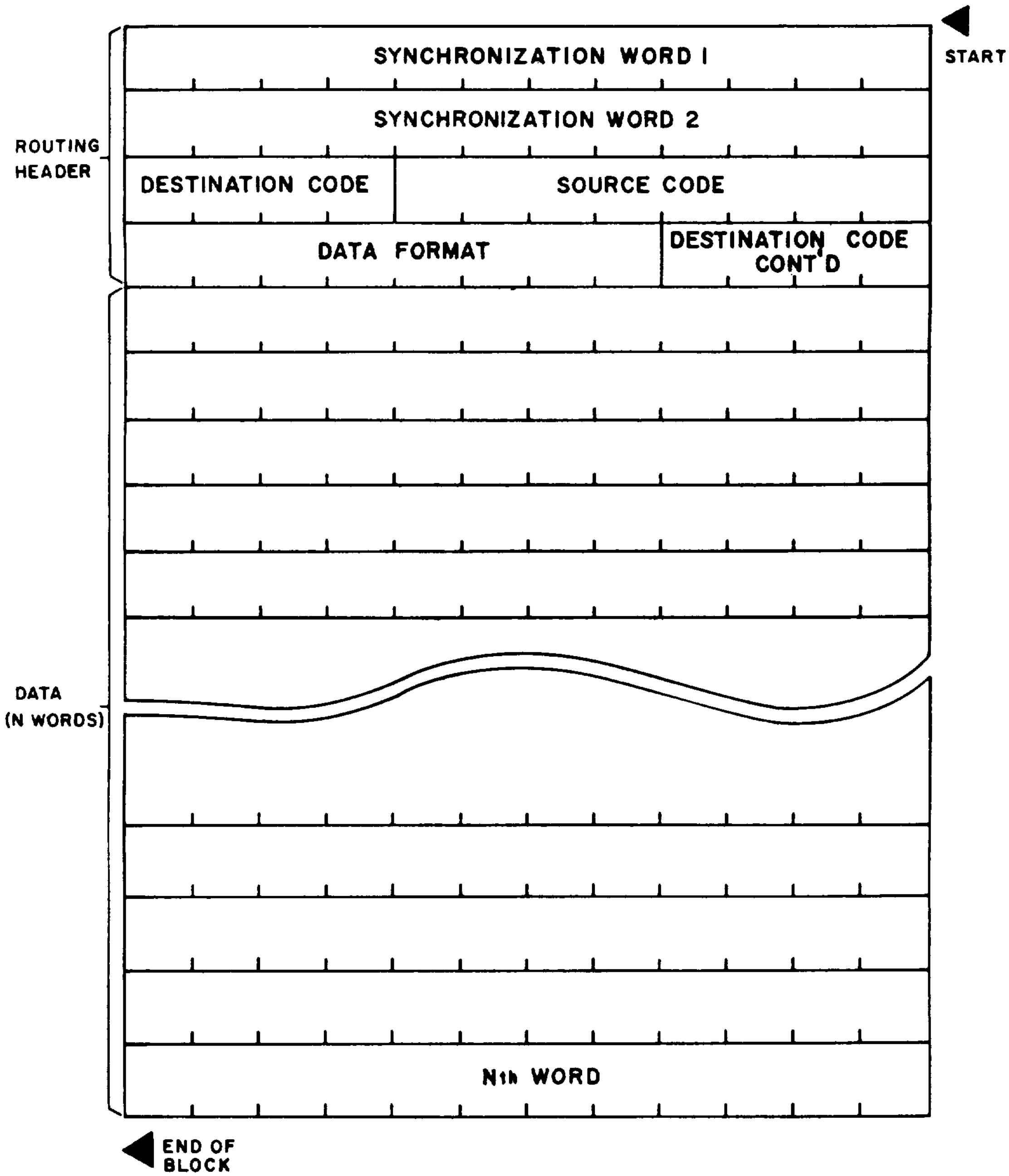


Figure 3-29. High-speed Data Format

3.9.5 NASCOM DATA SYSTEMS DEVELOPMENT PLAN

Current information regarding the available capabilities and existent implementation program of the NASCOM network may be found in the NASCOM Data Systems Development Plan (DSDP). This document is updated semi-annually. Requests for the NASCOM DSDP may be addressed to:

Code 840
Goddard Space Flight Center
Greenbelt, Maryland 20771
ATTN: Chief, NASA Comm. Division

3.10 ON-STATION COMMUNICATIONS SYSTEMS

3.10.1 INTERCOMMUNICATION SYSTEMS

The on-station intercommunications system at most USB-equipped stations consists of Western Electric (WECO) 112A key equipment, which is capable of two-wire and four-wire system operations. These systems normally have from 10 to 40 conference loops with 10 to 40 positions; cross-connects on the station provide for connecting any position to any conference loop in accordance with station or program requirements.

The use of a four-wire, four-way bridge provides for voice transmission with audible signaling among the project office, Network Operations Control Center (NOCC), GSFC voice control, and other stations. The WECO 112A key equipment is also compatible with the communications circuits of the NASCOM switching network. A position on the 112A key system is normally a four-wire circuit; however, positions can be connected to two-wire circuits and to a dial telephone system.

The patch and test board of the 112A key system can be used to patch voice and data transmission circuits to alternate routes or circuits in the event of prime route or circuit failure.

Stations which do not have the 112A equipment have a four/two wire intercommunications system. However, current plans call for updating these stations to a capability equivalent to that described above so that all network stations will have systems with similar capabilities.

3.10.2 VHF AIR-TO-GROUND VOICE COMMUNICATION

The S-band A-G voice communication link is detailed in para 3.2. The VHF A-G voice communication link is generally operated as a simplex system (transmit and receive on the same frequency); however, as there are two transmitters and two receivers at each manned flight support station, the equipment can be utilized for full duplex operation at stations with separate transmit and receive antennas. Also, the VHF A-G voice link has been used to transmit command data to an orbiting spacecraft, but such use in the future is not planned. Those stations having A-G voice capability are identified in table 1-2. VHF voice equipment currently in use throughout the network is as follows:

a. Transmitter and Linear Power Amplifier. The transmitter is a Model CM-580 20-watt multichannel unit with 3500 channels spaced at 50-kHz increments in the frequency range from 225 to 399.95 MHz. Any of the 3500 channels can be manually selected or the transmitter can be operated on any one of 24 preset channel frequencies. The AM signal is amplified by a Model CM-1680 100-watt linear amplifier fixed tuned to operate over the same frequency range as the transmitter. Remote keying of the transmitters can be accomplished by currently existing Quindar QR-30-28 tone receivers.

b. Receiver. The receiver is a solid state unit, Model CM-540, which operates over the same band and has channel options identical to those described for the CM-580 transmitter.

The above equipment is used at all A-G voice support stations except the Vanguard, the temporary station at Newfoundland, and the ARIA aircraft. Newfoundland has AN/URC-67 equipment with capabilities very similar to that previously described and the Vanguard has four AN/SCR-20 transceivers also with similar capabilities (100-watt, 225- to 399.9-MHz frequency range). The ARIA uses a Hallicrafter VHF voice transmitter, crystal controlled from 225 to 400 MHz, with a 100-watt linear amplifier and a TR 109 receiver with a 215- to 315-MHz tuning head.

3.11 TIMING SYSTEMS

3.11.1 GENERAL

Since the STDN stations are separated geographically to provide maximum tracking and telemetry data coverage of spacecraft, all time-referenced data must be synchronized from a common source. This is necessary for accurate predictions of spacecraft position and for evaluation of data received from a spacecraft. For this reason, the station time standards are synchronized to the U. S. Naval Observatory master clock located in Washington, D.C. Synchronization is accomplished via the standard frequency and time signal emissions from the National Bureau of Standards (NBS) radio stations WWV and WWVH and the low-frequency transmitted signals from the U.S. Naval Observatory controlled loran-C navigation systems. Coarse synchronization is accomplished via WWV/WWVH and fine synchronization via loran-C transmissions.

All STDN stations employ a cesium beam frequency standard as the primary source for time and time-interval measurements with rubidium atomic frequency standards as the first backup. In addition, at all former MSFN tracking stations, a highly stable oven-controlled quartz crystal frequency standard is available as a second backup. All stations have automatic switchover from primary to secondary frequency sources in event of a signal amplitude failure in the on-line frequency source. At all former MSFN stations, the secondary standards are phase locked to the primary standard which effectively eliminates frequency and time jumps in the event of switchover.

The accuracy of the network station clocks using the techniques described is 100 microseconds. This accuracy can be improved by a factor of two if post corrections of the reference time signals relative to the U.S. Naval Observatory master clock are made. For some stations this improvement can even be a factor of four, i.e., 25 microseconds. For automatic data processing using analog instrumentation tape recordings, the accuracy of the NASA time codes is generally 1 millisecond.

3.11.2 TIMING CODES

Timing codes generally available at all STDN stations are listed below and illustrated in figures 3-30 through 3-33.

a. NASA one-per-second BCD serial code.

b. NASA one-per-hour BCD serial code.

c. NASA Serial Decimal Time Code - A.

d. NASA Serial Decimal Time Code - B.

All of the above codes are available in dc level shift formats and as modulated carrier waveforms. It should be noted that the Serial Decimal Time Code is not identical at all stations. The code illustrated in figure 3-32 is generally available at former MSFN stations and the code in figure 3-33 at former STADAN stations.

Additional serial time codes available at some stations are tabulated in table 3-11 and parallel time information is supplied as indicated in table 3-12. These time codes are not standard NASA time codes. Their use in conjunction with GSFC data processing facilities and/or for project support requires a waiver from the GSFC Data Systems Requirements Committee.

In addition to time data, various sine-wave frequencies and pulse trains derived from the frequency standards are available for users. Three hydrogen maser frequency standards also are available for use at network stations to conduct such experiments as long baseline interferrometry to measure range or other applications requiring extreme frequency stability in the mid- and short-term ranges.

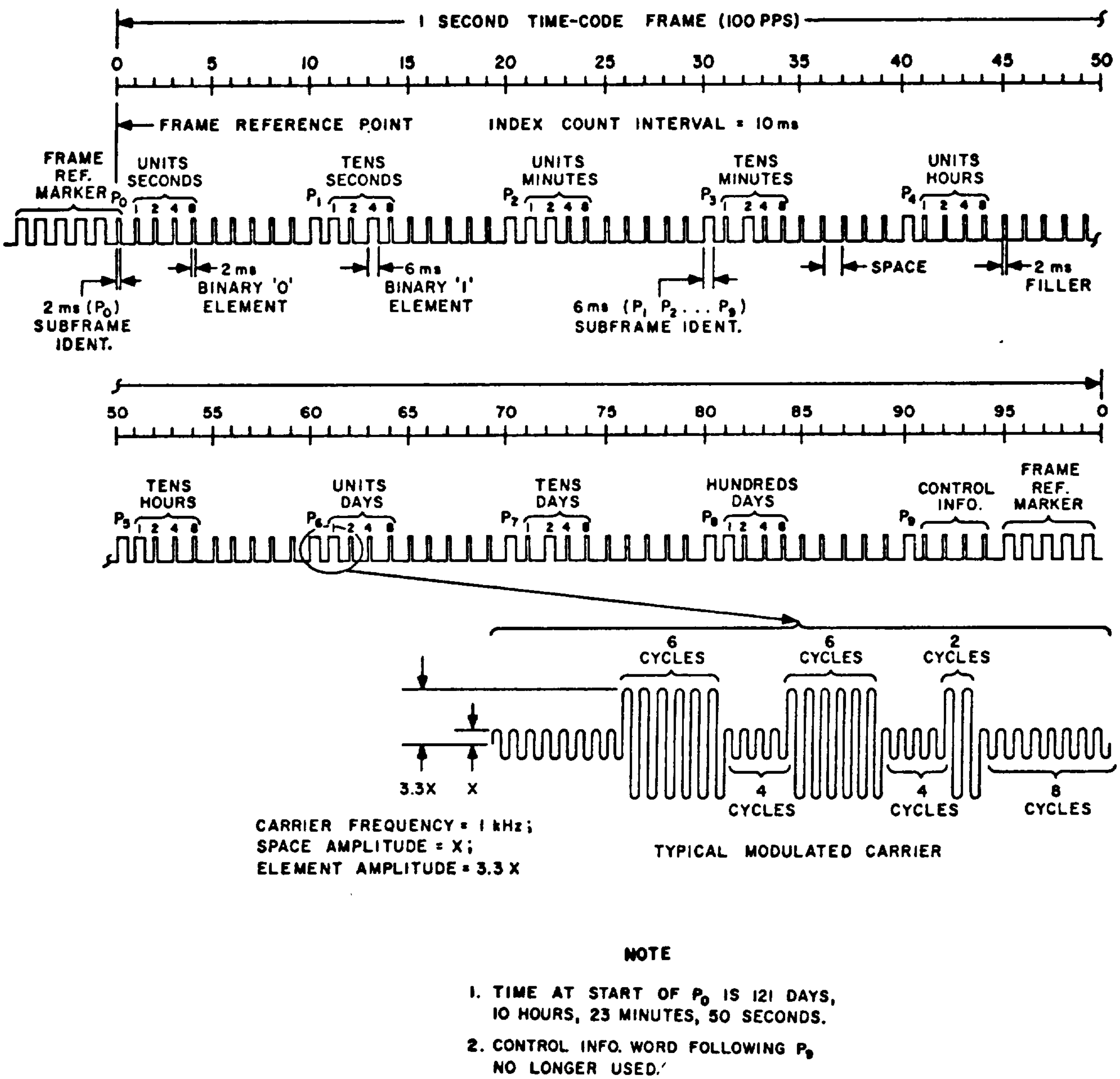
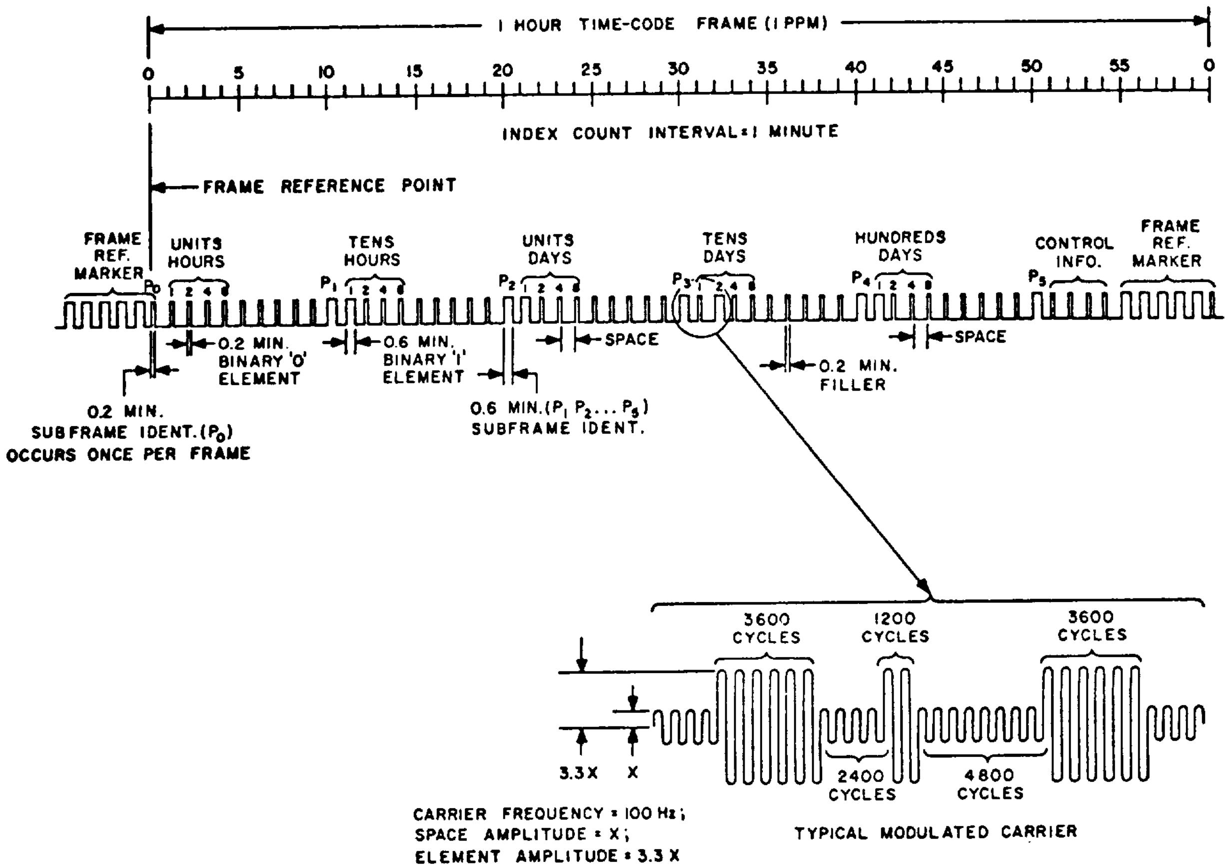


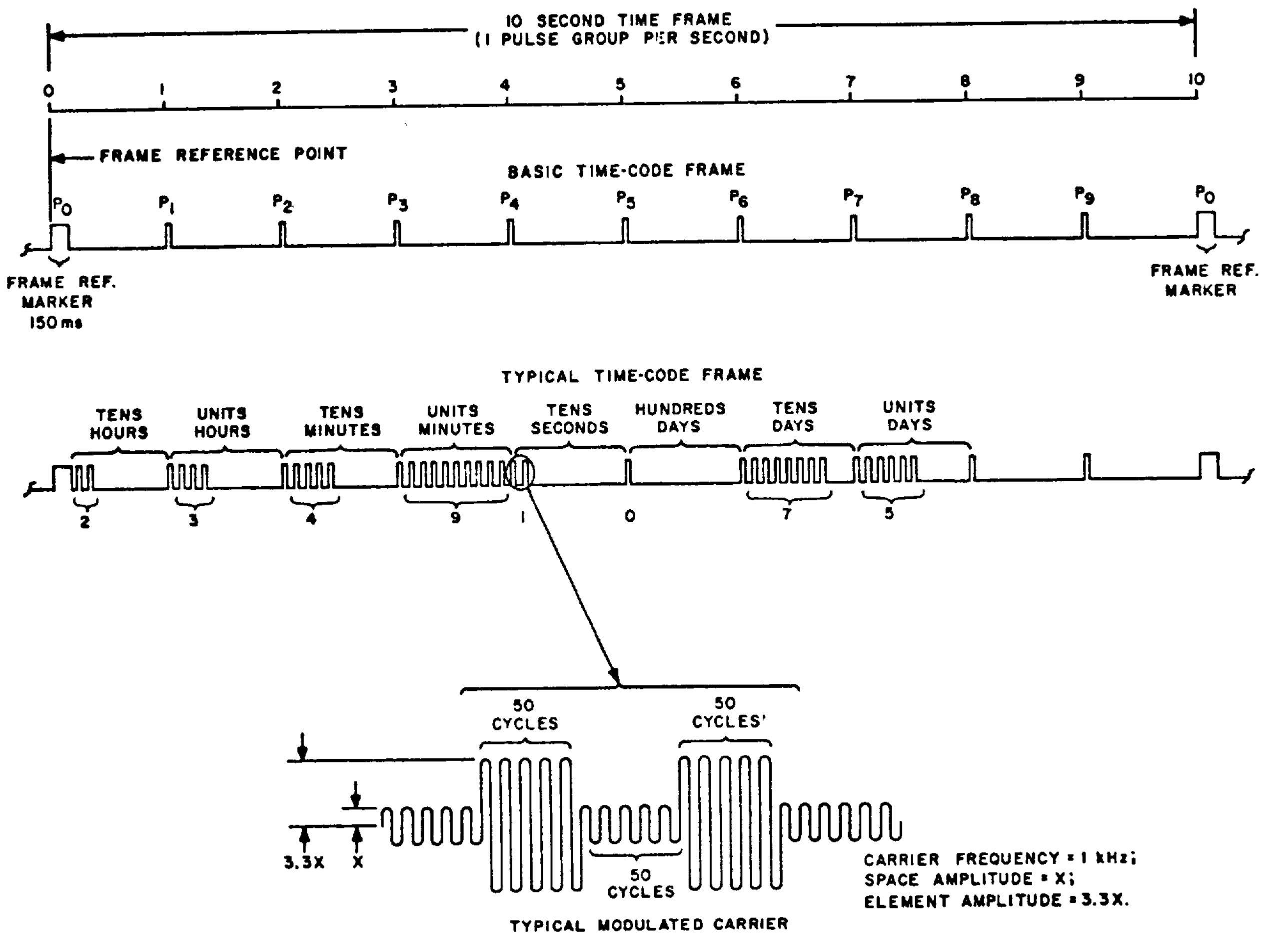
Figure 3-30. NASA One-per-second BCD Time Code



NOTE

1. TIME AT START OF P_0 IS 121 DAYS, 10 HOURS.
2. CONTROL INFO. WORD FOLLOWING P_5 NO LONGER USED

Figure 3-31. NASA One-per-hour BCD Time Code



NOTE

1. $P_0, P_1, \cdots P_9$ ARE PULSE GROUP IDENTIFIERS.
2. ALL ELEMENTS AND SPACES EXCEPT THE FRAME REFERENCE MARKER ARE 50ms WIDE.
3. TIME AT THE FRAME REFERENCE MARKER IS 75 DAYS, 23 HOURS, 49 MINUTES, 10 SECONDS.

Figure 3-32. NASA Serial Decimal Time Code-A

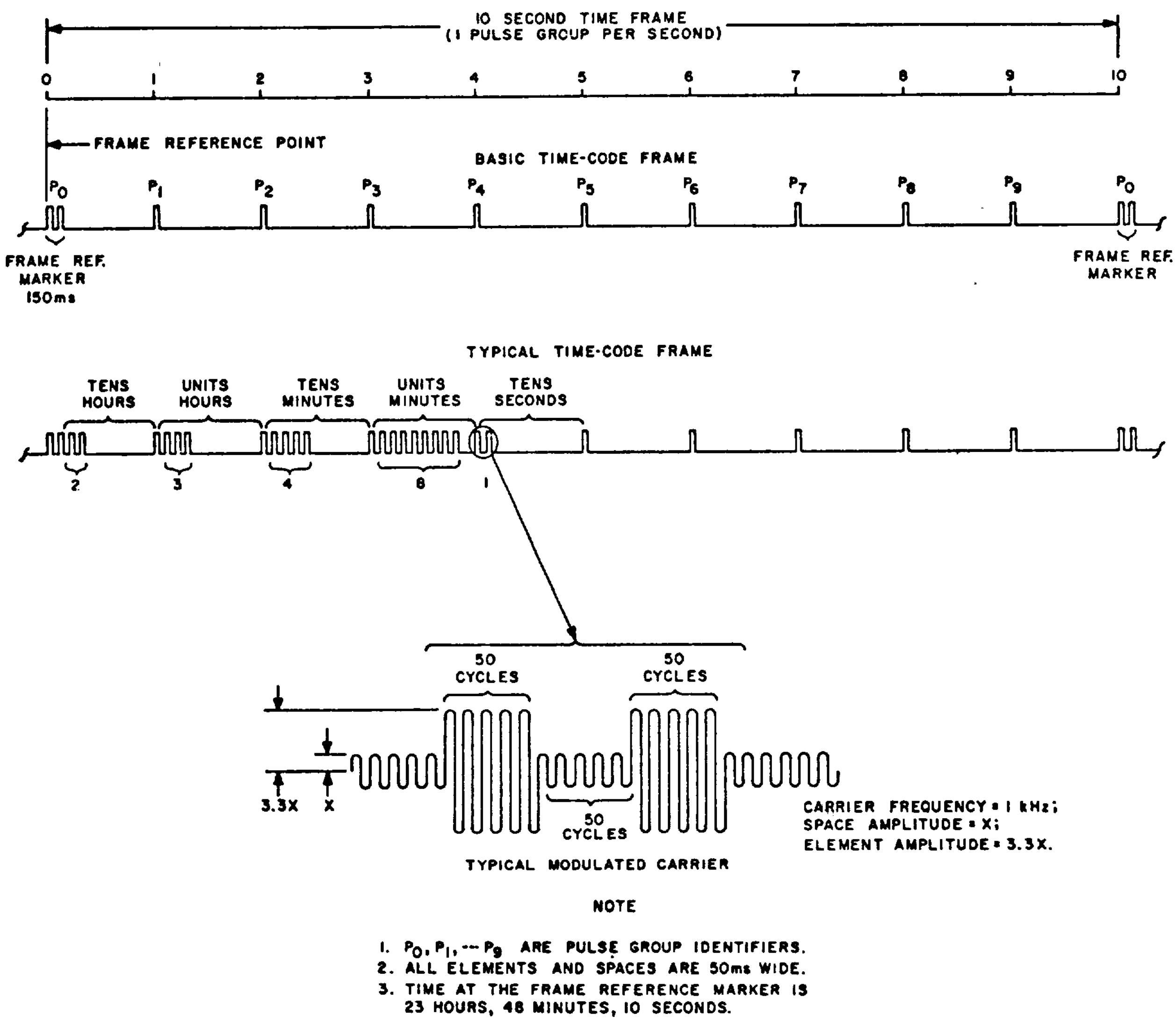


Figure 3-33. NASA Serial Decimal Time Code-B

Table 3-11. Serial Time Codes

Code	Station	
	Former MSFN	VAN
Binary Second of Year	X	X
Binary Tenth of Second Year	X	X
Binary Millisecond of Year	X	
Binary Coded Group Time of Year		X
Binary Second of Day		X
IRIG B	X*	
IRIG A through E	**	X

* This is available on a limited time share basis from the tape search system which is normally used in conjunction with telemetry for time tagging magnetic tapes.

**HAW also has IRIG's A through E.

Table 3-12. Parallel Time Data

Code	Format	Stations		
		Former STADAN	Former MSFN	VAN
Time of Year (1 sec resolution)	BCD, 30 bit (1,2,4,8)	X	X	X
Time of Year (1 millisec resolution)	BCD, 42 bit (1,2,4,8)	X		
Time of Year (to 1 sec)	Binary, 25 bit		X	X
Time of Year (to 0.1 sec)	Binary, 29 bit		X	
Time of Year (to 0.001 sec)	Binary, 35 bit		X	
Ground Elapse Time	BCD, (26 or 31 bits)		X	X
Horizon Time	BCD, 26 bits		X*	X
Hold Time	BCD, 22 bits		X	

*MIL only.

Appendix A. TDRSS/User Link Calculations

This appendix is from the Brief TDRSS Users Guide, dated October 1973. This document and other TDRSS planning information is available through the TDRSS study office, Code 805, Goddard Space Flight Center, Greenbelt, Maryland 20771.

1. GENERAL

This appendix contains the TDRSS/user link calculations. The calculations, which are based on state-of-the-art communications terminals on the user spacecraft, show available telemetry or command data rates (without spectrum spreading) as a function of user antenna gain (forward link) or user EIRP (return link). The links are based on achieving the indicated Bit Error Rate (BER) for the available data rate, and assume the worst-case channel characteristics. Each calculation contains a 3-dB margin. Tables A-1 through A-8 contain the calculations for each link, while figures A-1 through A-8 graphically illustrate each calculation.

2. PARAMETER DEFINITIONS

2.1 FORWARD LINKS

The following parameters are used in the calculations for the forward links (not all parameters are included in each calculation):

a. BER - Bit Error Rate

b. TDRSS Antenna Gain - For multiple-access, the gain at the 3-dB point; for single-access, the on-axis gain.

c. TDRSS Transmit Power - Power out of the TDRSS transmitter.

d. RF Losses - TDRSS RF losses between the transmitter and the antenna.

e. Pointing Losses - Losses resulting from antenna pointing inaccuracy.

f. EIRP - Effective Isotropic Radiated Power of TDRS.

g. Space Loss - Space loss on TDRS/user link.

h. User Antenna Gain - Gain of user antenna in direction of TDRS.

i. Polarization Loss - Losses resulting from misalignment of polarization vector between TDRS and user.

k. P_s out of User Antenna - RF power at output terminal of user antenna.

l. T_s - Noise temperature at output terminal of user antenna (includes line losses).

m. KT_s - Noise power at output terminal of user antenna.

n. P_s/KT_s - Signal-to-noise ratio at output of user antenna.

o. Transponder Loss - Multiplexing, demultiplexing, and tandem link loss on user spacecraft.

p. Demodulation Loss - Degradation of BER in digital demodulator/bit synchronizer on user spacecraft.

q. PN Loss - Degradation caused by correlation process on user spacecraft.

r. Residual Carrier Loss - Modulation loss.

s. System Margin - System operating margin.

t. Required E_b/N_o - Bit signal-to-noise ratio required to achieve the given BER.

u. Forward Error Control (FEC) Gain - FEC coding gain.

2.2 RETURN LINKS

The following parameters are used in the calculations for the return links:

a. BER - Bit Error Rate

b. User EIRP - Effective Isotropic Radiated Power of user spacecraft.

c. Space Loss - Space loss on TDRS/user link.

d. Pointing Loss - Losses resulting from antenna pointing inaccuracy.

e. Polarization Losses - Losses resulting from misalignment of polarization vector between TDRS and user.

f. TDRS Antenna Gain - For multiple-access, the gain at the 3-dB point; for single-access, the on-axis gain.

g. P_s at Output of Antenna - RF power at terminals of TDRS antenna.

h. T_i - Equivalent noise temperature at output of TDRS antenna due to presence of other user signals.

i. T_s - Noise temperature at terminal of TDRS antenna, including line losses (thermal noise). The T_s calculation in the single-access return link (Ku-band) is:

$$T_s = 253 + 290\ (0.6) + T_e\ (1.6) + T_e\ (1.6)\ (0.03)$$

$$= 253 + 193 + 240 + 24$$

$$= 710^\circ$$ (445° at input to preamp, assumed line loss of 2 dB)

The T_s calculation for the S-band return links is:

$$T_s = 234 + 290\ (0.6) + T_e\ (1.6) + T_e\ (1.6)\ (0.03)$$

$$= 234 + 193 + 400 + 16.8$$

$$= 824^\circ$$ (520° at input of preamplifier, assumed line loss of 2 dB)

j. $K(T_s+T_i)$ - Total noise power (all sources) at output of TDRS antenna.

k. Transponder Loss - Multiplexing, demultiplexing, and tandem link loss on TDRS.

l. Demodulation Loss - Degradation of BER in digital demodulator/bit synchronizer at TDRSS ground terminal.

m. PN Loss - Degradation caused by correlation process at TDRSS ground terminal.

n. Residual Carrier Loss - Modulation loss.

o. AGIPA Loss - Applies to the multiple-access system only, loss in AGIPA processor.

p. System Margin - System operating margin.

q. Required E_b/N_o - Bit signal-to-noise ratio required to achieve the given BER.

r. FEC Gain - FEC coding gain.

Table A-1. Calculation for Multiple-access Forward Link, S-band

BER	10^{-5}
TDRS Transmit Power (dBW), 19.5 W	12.9
RF Losses (dB)	-1.0
TDRS Antenna Gain ($\pm 13^{o}$)	13.0
EIRP (dBW)	24.9
Space Loss (dB)	-191.6
User Antenna Gain (dB)	G_u
P_s out of User Antenna (dBW)	$-166.7 + G_u$
T_s (Antenna Output Terminal)	824^{o}
KT_s (dBW)	-199.4
P_s/KT_s (dB/Hz)	$32.7 + G_u$
Transponder Loss (dB)	-1.0
Demodulation Loss (dB)	-1.5
PN Loss (dB)	-1.0
System Margin (dB)	-3.0
Required E_b/N_o, Δ PSK	-9.9
Achievable Data Rate (dB)	$16.3 + G_u$
FEC Gain, R = 2, K = 7 (dB)	5.2
Achievable Data Rate (dB)	$21.5 + G_u$
FEC Gain, R = 3, K = 7 (dB)	5.7
Achievable Data Rate (dB)	$22.0 + G_u$

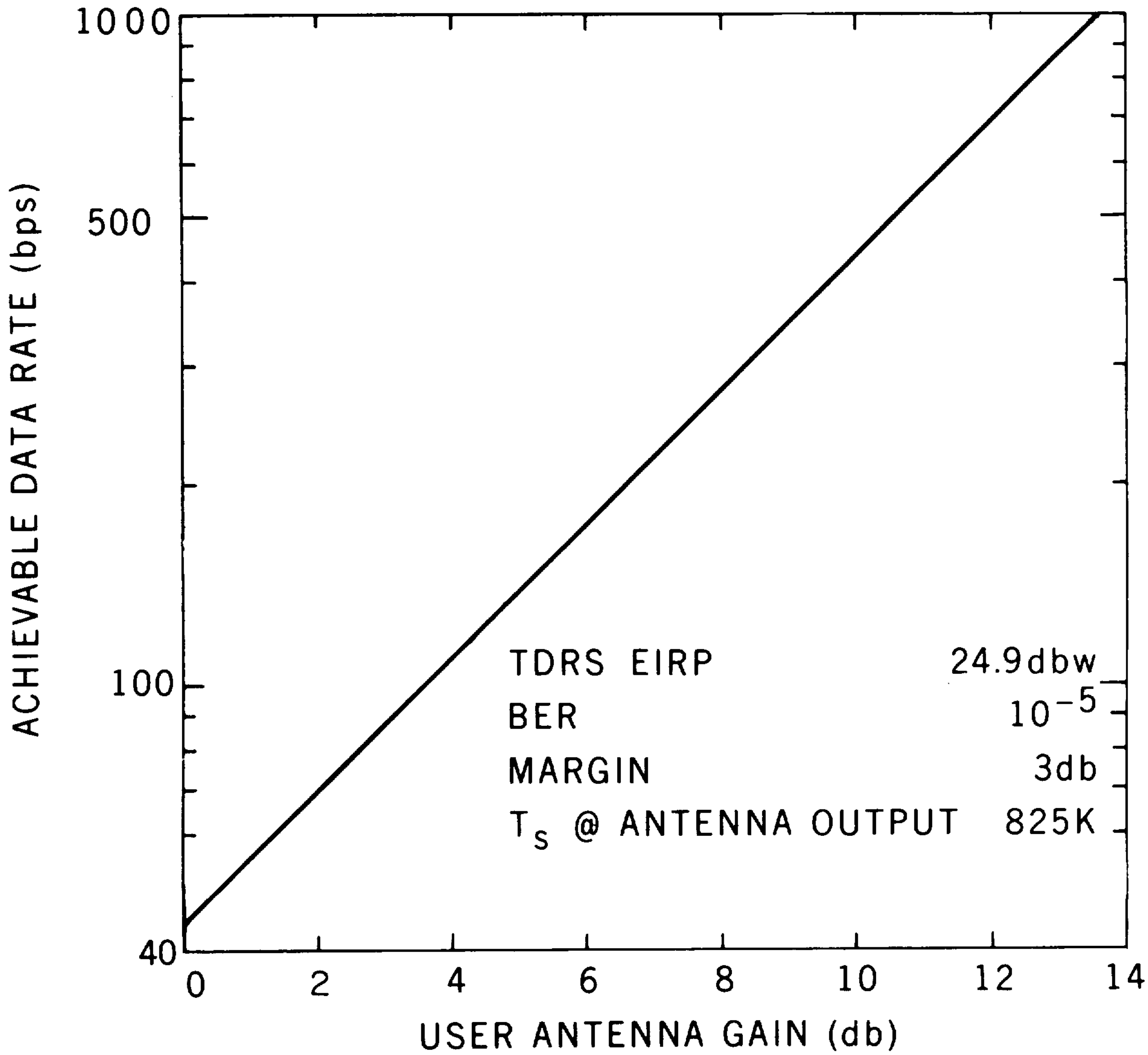


Figure A-1. Multiple-access Forward Link (S-band), Achievable Data Rate vs User Antenna Gain

Table A-2. Calculation for Single-access Forward Link, S-band

Parameter	Low Power	High Power
BER	10^{-5}	10^{-5}
TDRSS Antenna Gain	35.4 (50%)*	35.4 (50%)
TDRSS Transmit Power (dBW)	5.5	11.5
RF Losses (Transmit) (dB)	-2	-2
Pointing Loss (dB)	-0.5	-.05
EIRP (dBW)	38.4	44.4
Space Loss (dB)	-191.6	-191.6
User Antenna Gain (dB)	G_u	G_u
Polarization Loss (dB)	-0.5	-0.5
P_s out of User Antenna (dBW)	$-153.7 + G_u$	$-147.7 + G_u$
T_s (Output of Antenna) (^oK)	824	824
T_s (dB)	29.2	29.2
KT_s (dBW)	-199.4	-199.4
P_s/KT_s (dB/Hz)	$45.7 + G_u$	$51.7 + G_u$
Transponder Loss (dB)	-1.0	-1.0
Demodulation Loss (dB)	-1.5	-1.5
PN Loss (dB)	-1.0	-1.0
Residual Carrier Loss (dB)	0	0
System Margin (dB)	-3.0	-3.0
Required E_b/N_o, ΔPSK	-9.9	-9.9
Achievable Data Rate (dB)	$29.3 + G_u$	$35.3 + G_u$
FEC Gain, R = 2, K = 7 (dB)	5.2	5.2
Achievable Data Rate (dB)	$34.5 + G_u$	$40.5 + G_u$
FEC Gain, R = 3, K = 7 (dB)	5.7	5.7
Achievable Data Rate (dB)	$35.0 + G_u$	$41.0 + G_u$

* On-axis.

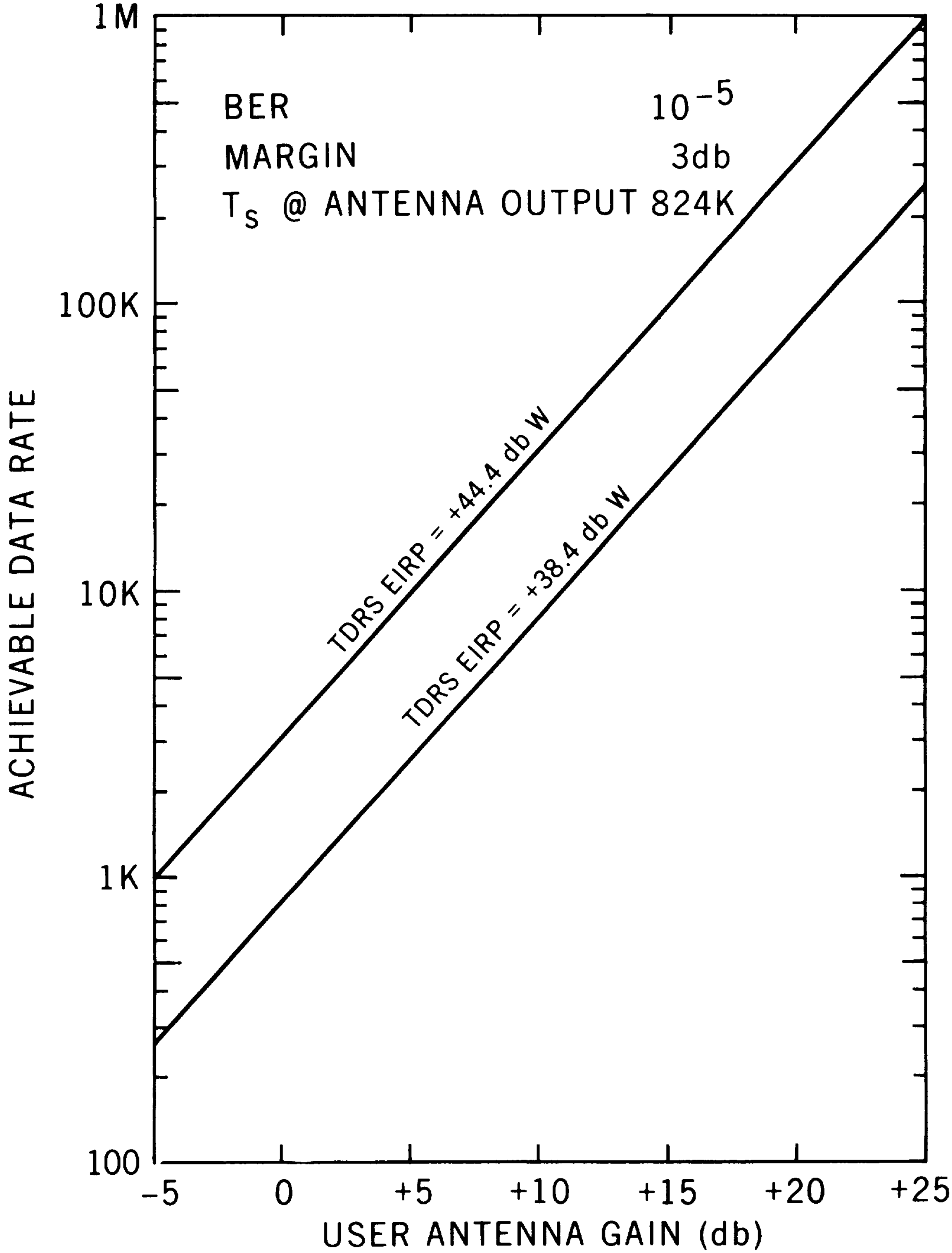


Figure A-2. Single-access (S-band) Forward Link, Achievable Data Rate vs User Antenna Gain

Table A-3. Calculation for Single-access Forward Link, Ku-band

Parameter	Low	High
BER	10^{-5}	10^{-5}
TDRSS Antenna Gain	52.0 (55%)*	52.0 (55%)*
TDRSS Transmit Power (dBW)	-20	0
RF Losses (Transmit) (dB)	-2	-2
Pointing Loss (dB)	-0.5	-0.5
EIRP (dBW)	29.5	49.5
Space Loss (dB)	-208.6	-208.6
User Antenna Gain (dB)	G_u	G_u
Polarization Loss (dB)	-0.5	-0.5
P_s Out of User Antenna (dBW)	$-179.6 + G_u$	$-159.6 + G_u$
T_s (Output of Antenna) (^oK)	710	710
T_s (dB)	28.5	28.5
KT_s (dBW)	-200.1	-200.1
P_s/KT_s (dB/Hz)	$20.5 + G_u$	$40.5 + G_u$
Transponder Loss (dB)	-1.0	-1.0
Demodulation Loss (dB)	-1.5	-1.5
PN Loss (dB)	-1.0	-1.0
Residual Carrier Loss (dB)	-1.0	-1.0
System Margin (dB)	-3.0	-3.0
Required E_b/N_o, Δ PSK	-9.9	-9.9
Achievable Data Rate (dB)	$3.1 + G_u$	$23.1 + G_u$
FEC Gain, R = 2, K = 7 (dB)	5.2	5.2
Achievable Data Rate (dB)	$8.3 + G_u$	$28.3 + G_u$
FEC Gain, R = 3, K = 7 (dB)	5.7	5.7
Achievable Data Rate (dB)	$8.8 + G_u$	$28.8 + G_u$

*On axis.

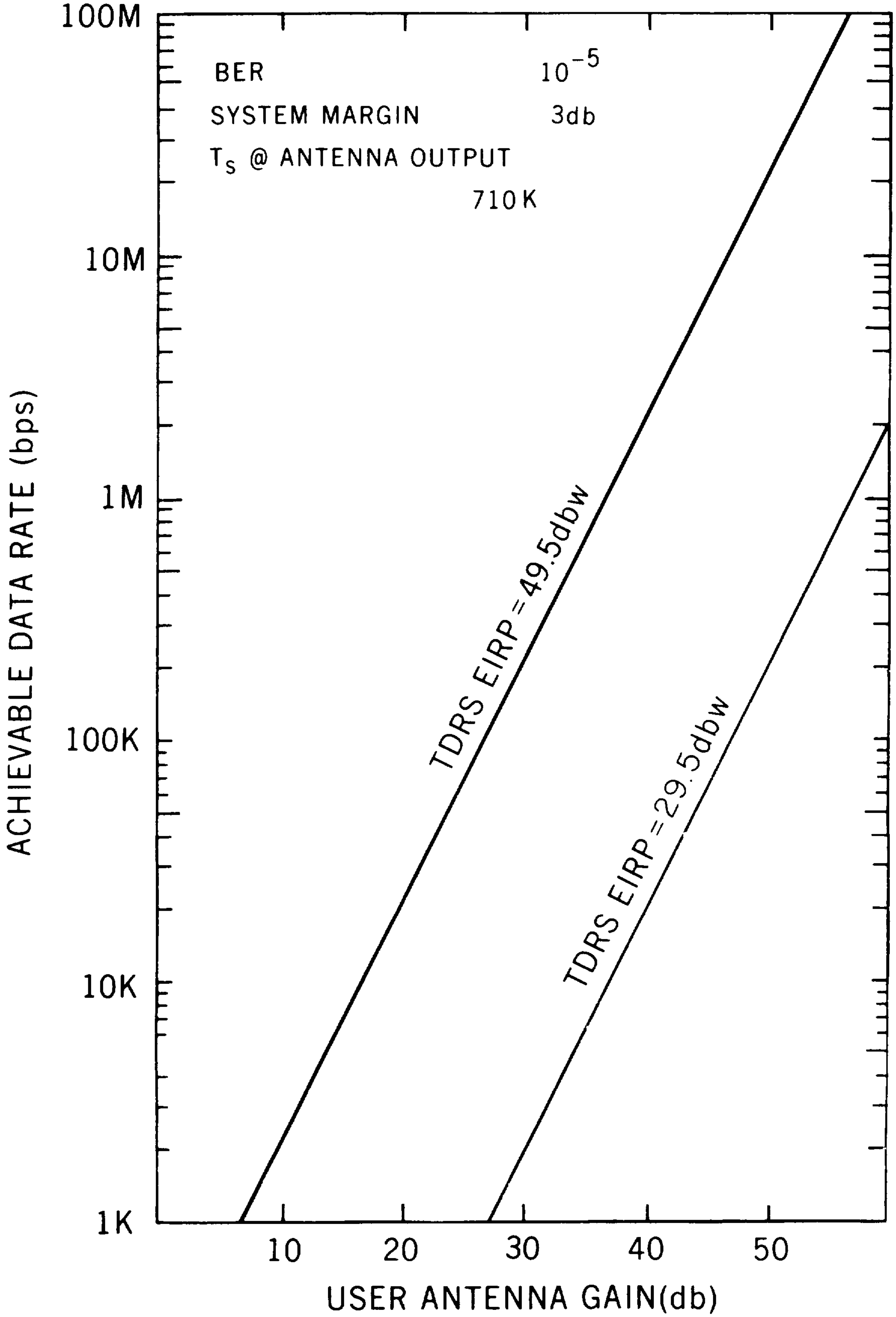


Figure A-3. Single-access (Ku-band) Forward Link, Achievable Data Rate vs User Antenna Gain

Table A-4. Calculation for Single-access Forward Link S-band, Shuttle

BER	10^{-5}
TDRSS Antenna Gain	35.4 (50%)*
TDRSS Transmit Power (dBW)	11.5
RF Losses (Transmit) (dB)	-2
Pointing Loss (dB)	-0.5
EIRP (dBW)	44.4
Space Loss (dB)	-191.6
User Antenna Gain (dB)	G_u
Polarization Loss (dB)	-0.5
P_s out of User Antenna (dBW)	$-147.7 + G_u$
T_s (Output of Antenna)	540
T_s (dB)	27.3
KT_s (dBW)	-201.3
P_s/KT_s (dB/Hz)	$53.6 + G_u$
Transponder Loss (dB)	-1.0
Demodulation Loss (dB)	-1.5
PN Loss (dB)	-1.0
Residual Carrier Loss (dB)	0
System Margin (dB)	-3.0
Required E_b/N_o, ΔPSK	-9.9
Achievable Data Rate (dB)	$37.2 + G_u$
FEC Gain, R = 2, K = 7 (dB)	5.2
Achievable Data Rate (dB)	$42.4 + G_u$
FEC Gain, R = 3, K = 7 (dB)	5.7
Achievable Data Rate (dB)	$42.9 + G_u$

*On axis.

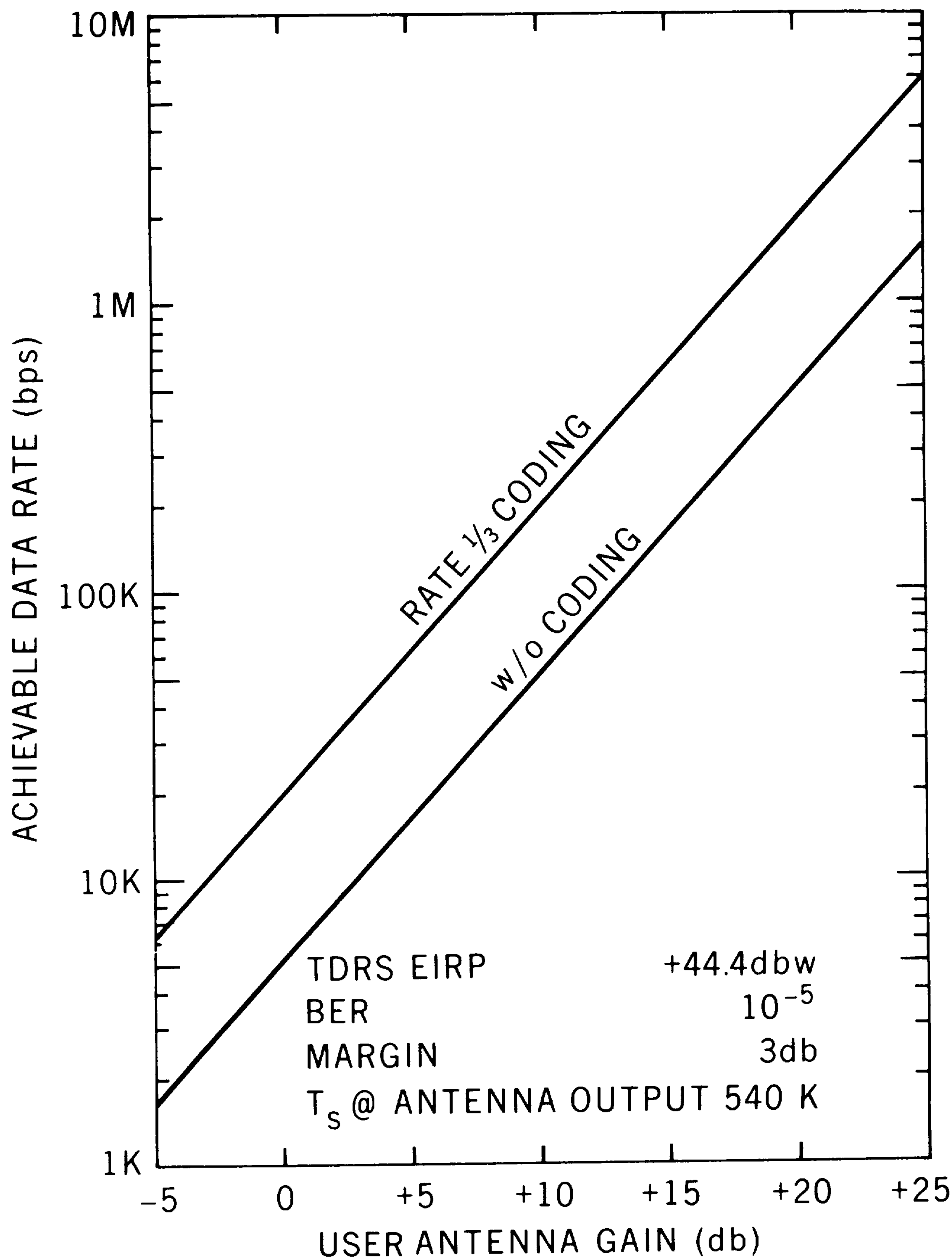


Figure A-4. Single-access (S-band Shuttle Forward Link, Achievable Data Rate vs User Antenna Gain

Table A-5. Calculation for Multiple-access Return Link, S-band

BER	10^{-5}
User EIRP (dBW)	EIRP
Space Loss (dB)	-192.2
Polarization Loss (dB)	-1.0
TDRS Antenna Gain @ $\pm 13^{o}$ (dB)	28.0
P_s at Output of Antenna (dBW)	-165.2 + EIRP
T_i (antenna output terminals) (^{o}K)	824
T (due to direct other user interference)	255
$K(T_s + T_i)$ (dBW)	-198.3
$P_s/K(T_s + T_i)$	+33.1 + EIRP
Transponder Loss (dB)	-2.0
Demodulation Loss (dB)	-1.5
PN Loss (dB)	-1.0
AGIPA Loss (dB)	-0.5
System Margin (dB)	-3.0
Required E_b/N_o(10 BER), Δ PSK	-9.9
Achievable Data Rate (dB)	+15.2 + EIRP
FEC Gain, R = 2, K = 7 (dB)	5.2
Achievable Data Rate (dB)	+20.4 + EIRP
FEC Gain, R = 3, K = 7 (dB)	5.7
Achievable Data Rate (dB)	+20.9 + EIRP

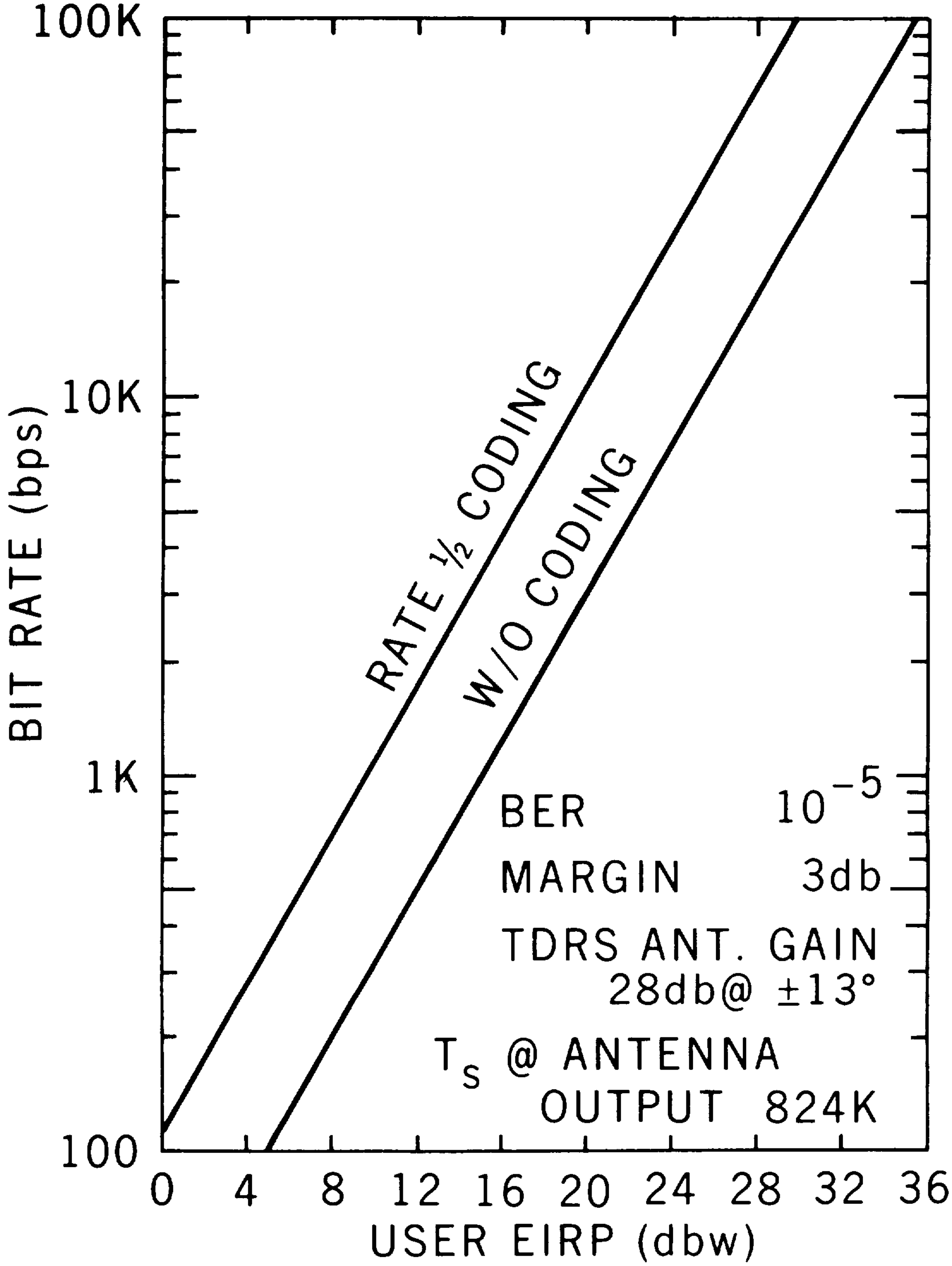


Figure A-5. Multiple-access (S-band) Return Link,
Data Rate vs User EIRP

Table A-6. Calculation for Single-access Return Link, S-band

BER	10^{-5}
User EIRP	EIRP
Space Loss (dB)	-192.2
Pointing Loss (dB)	-0.5
Pol. Loss (dB)	-0.5
TDRS Antenna Gain (dB)	36.0 (50%)*
P_s at Output of Antenna (dBW)	-157.2 + EIRP
T_i (because of direct other user interference) (^{o}K)	----
T_s (Antenna Output Terminals) (^{o}K)	824
KT_s at Output of Antenna	-199.4
P_s/KT_s	42.2 + EIRP
Transponder Loss (dB)	-2.0
Demodulation Loss (dB)	-1.5
PN Loss (dB)	0.0
Residual Carrier Loss (dB)	0
AGIPA Loss (dB)	
System Margin (dB)	-3.0
Required E_b/N_o, ΔPSK	-9.9
Achievable Data Rate (dB)	25.8 + EIRP
FEC Gain, R = 2, K = 7 (dB)	5.2
Achievable Data Rate (dB)	31.0 + EIRP
FEC Gain, R = 3, K = 7 (dB)	5.7
Achievable Data Rate (dB)	31.5 + EIRP

* On axis.

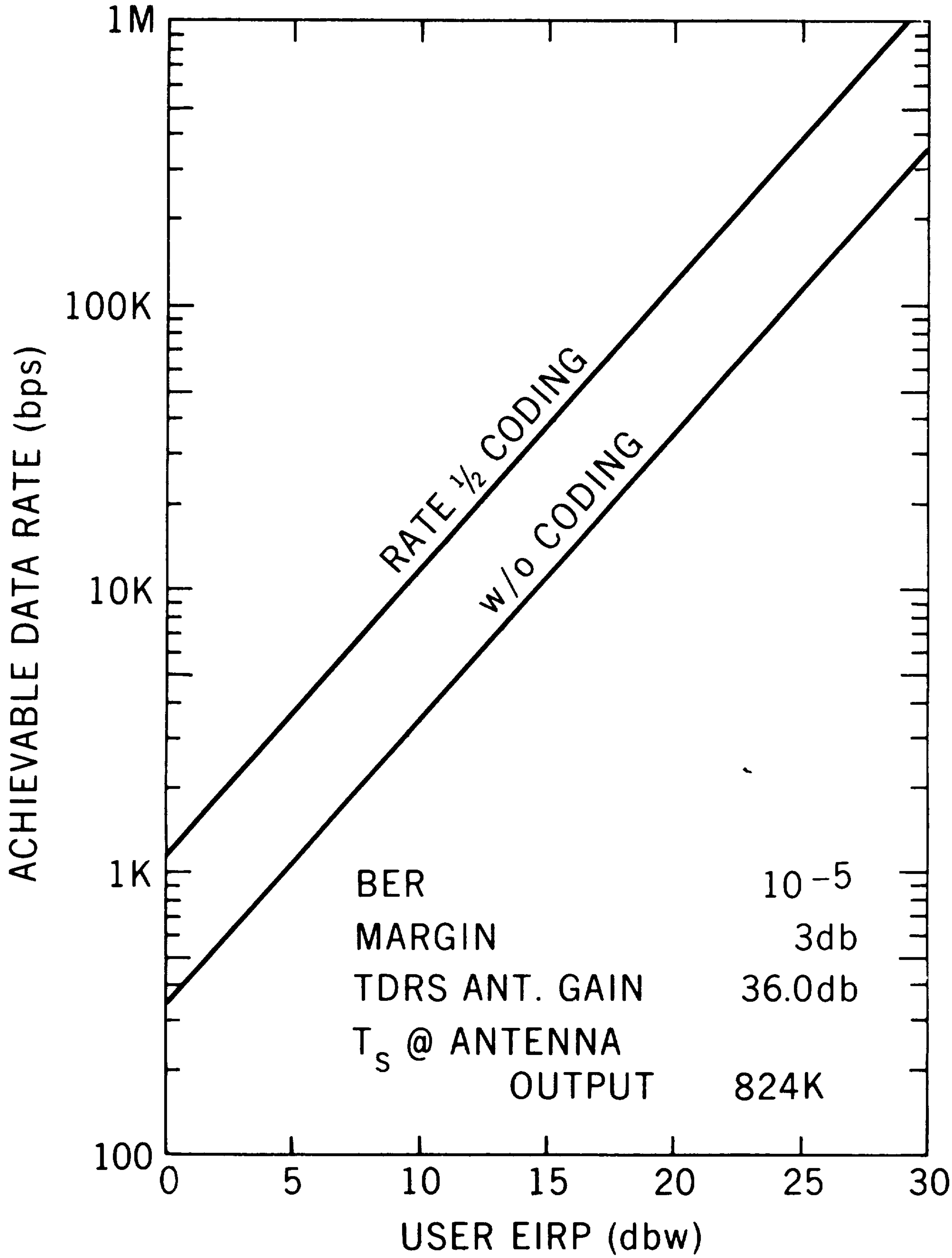


Figure A-6. Single-access (S-band) Return Link, Achievable Data Rate vs User EIRP

Table A-7. Calculation for Single-access Return Link, Ku-band

BER	10^{-5}
User EIRP (dBW)	EIRP
Space Loss (dB)	-209.2
Pointing Loss (dB)	-0.5
Pol. Loss (dB)	-0.5
TDRS Antenna Gain (dB)	52.6 (55%)*
P_s at Output of Antenna (dBW)	-157.6 + EIRP
T_i (because of direct other user interference)	----
T_s (Antenna Output Terminals) (^oK)	710
KT_s at Output of Antenna	-200.1
P_s/KT_s	42.5 + EIRP
Transponder Loss (dB)	-2.0
Demodulation Loss (dB)	-1.5
PN Loss (dB)	0
Residual Carrier Loss (dB)	-1.0
AGIPA Loss (dB)	
System Margin (dB)	-3.0
Required E_b/N_o, Δ PSK	-9.9
Achievable Data Rate (dB)	25.1 + EIRP
FEC Gain, R = 2, K = 7 (dB)	5.2
Achievable Data Rate (dB)	30.3 + EIRP
FEC Gain, R = 3, K = 7 (dB)	5.7
Achievable Data Rate (dB)	30.8 + EIRP

*On axis.

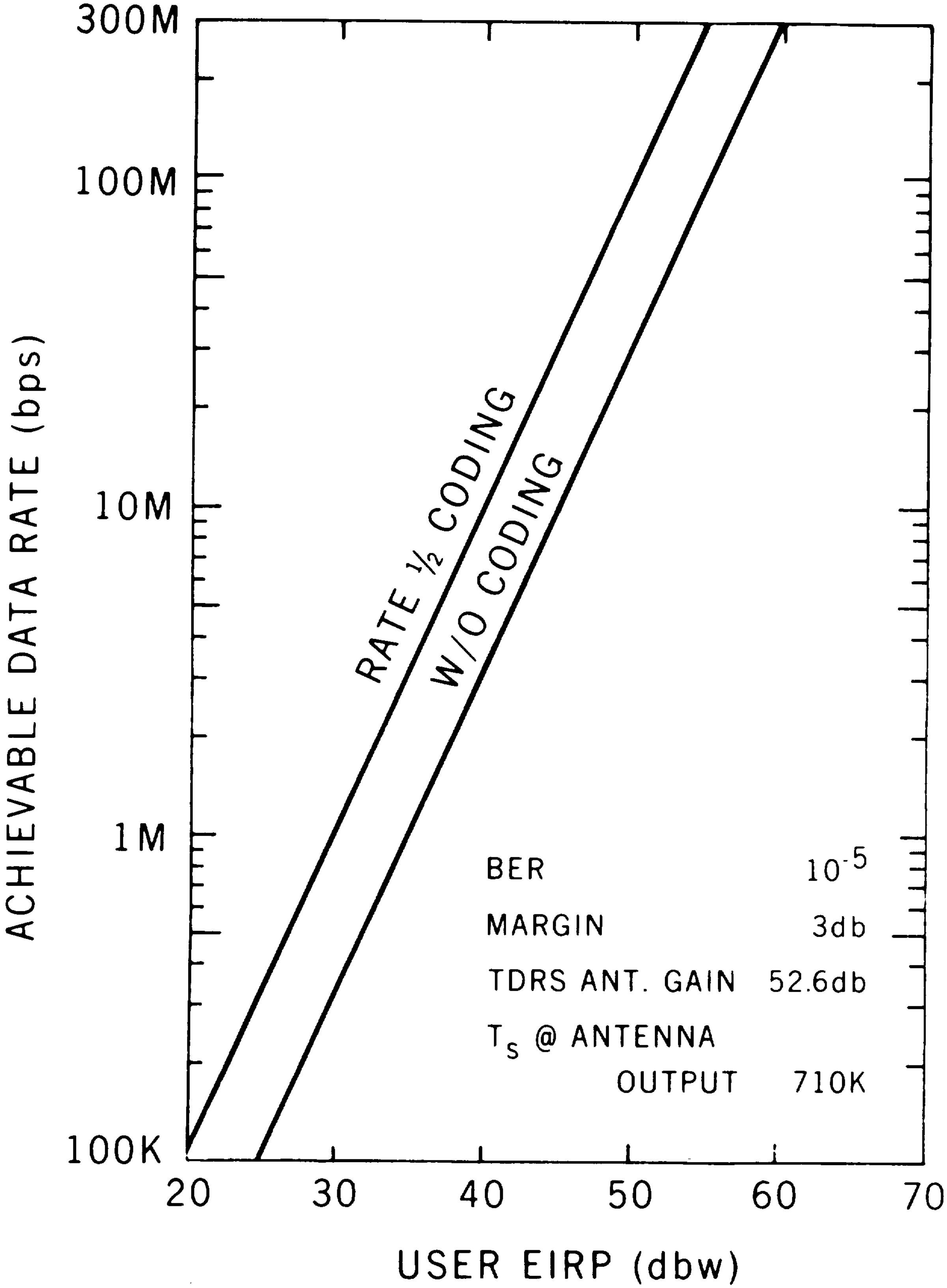


Figure A-7. Single-access (Ku-band) Return Link, Achievable Data Rate vs User EIRP

Table A-8. Calculation for Single-access Return Link, S-band Shuttle

BER	10^{-5}
User EIRP (dBW)	EIRP
Space Loss (dB)	-192.2
Pointing Loss (dB)	-0.5
Pol. Loss (dB)	-0.5
TDRS Antenna Gain (dB)	36.0 (50%)*
P_s at Output of Antenna (dBW)	-157.2 + EIRP
T_i (because of direct other user interference) (^oK)	----
T_s (Antenna Output Terminals) (^oK)	824
KT_s at Output of Antenna	-199.4
P_s/KT_s	42.2 + EIRP
Transponder Loss (dB)	-2.0
Demodulation Loss (dB)	-1.5
PN Loss (dB)	0
Residual Carrier Loss (dB)	-1.0
AGIPA Loss (dB)	
System Margin (dB)	-3.0
Required E_b/N_o, Δ PSK	-9.9
Achievable Data Rate (dB)	24.8 + EIRP
FEC Gain, R = 2, K - 7 (dB)	5.2
Achievable Data Rate (dB)	30.0 + EIRP
FEC Gain, R = 3, K = 7 (dB)	5.7
Achievable Data Rate (dB)	30.5 + EIRP

* On axis.

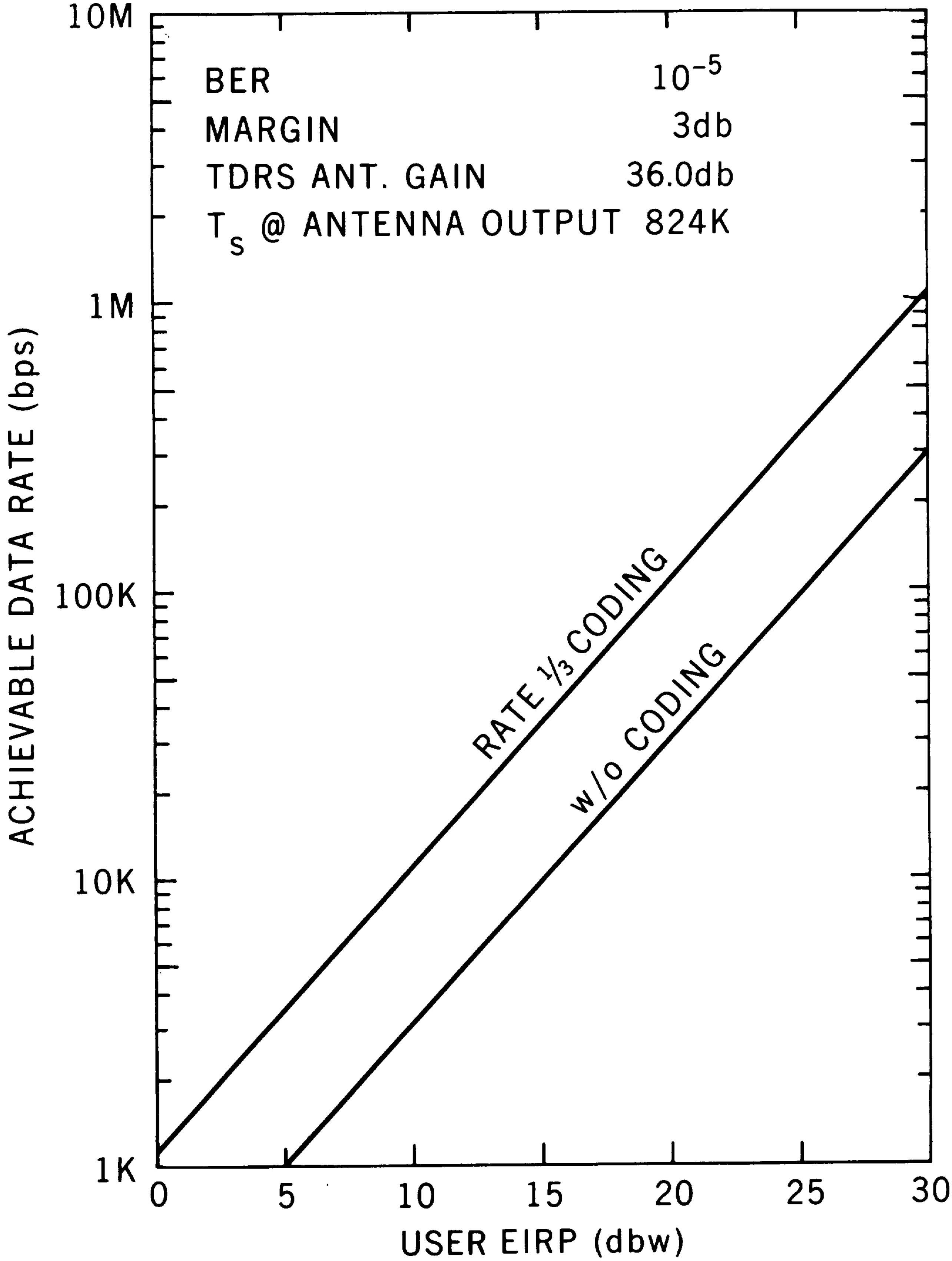


Figure A-8. Single-access (S-band) Shuttle Return Link, Achievable Data Rate vs User EIRP

Appendix B. Slant Range Computation Charts

This appendix provides a set of charts from which spacecraft slant ranges computations may be made. Figures B-1, B-2, and B-3 give the results in kilometers and figures B-4, B-5, and B-6 give the same data in nautical miles. (These charts are from NASA/GSFC document X-860-73-124, Slant Range vs Altitude and Elevation Angle-A Convenient Set of Charts.

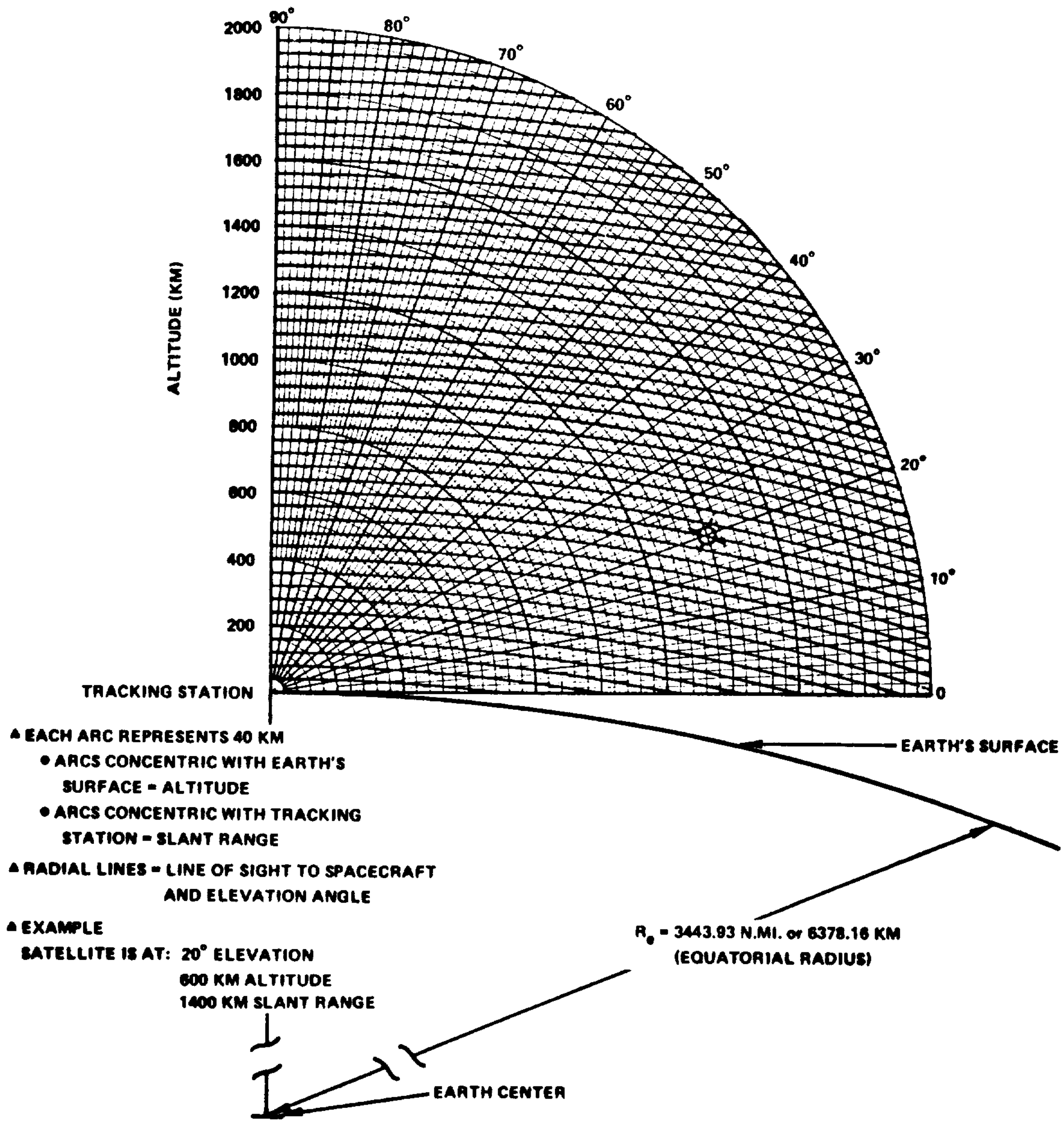


Figure B-1. Slant Range (km) Chart for Altitude up to 2,000 km

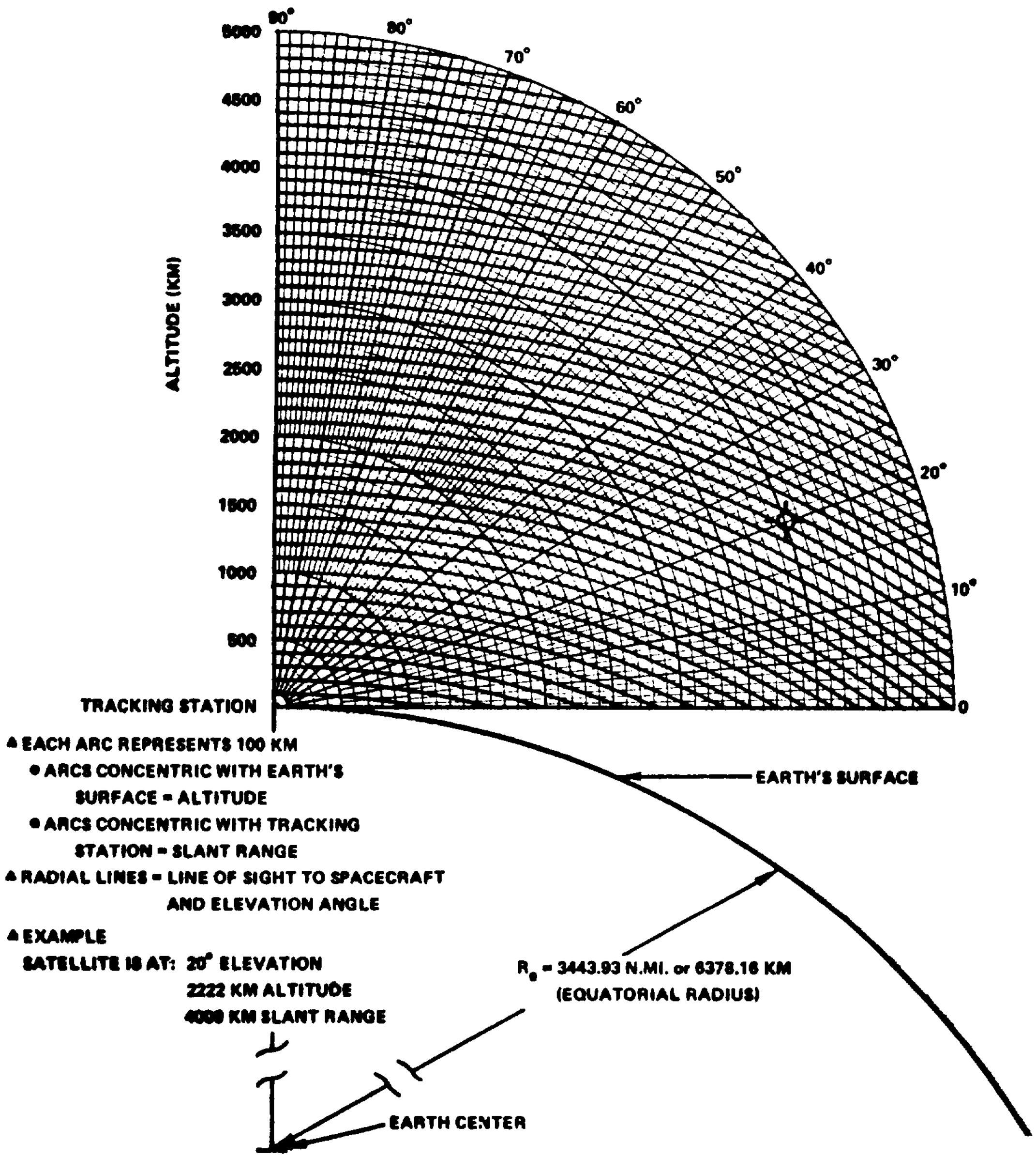


Figure B-2. Slant Range (km) Chart for Altitude up to 5,000 km

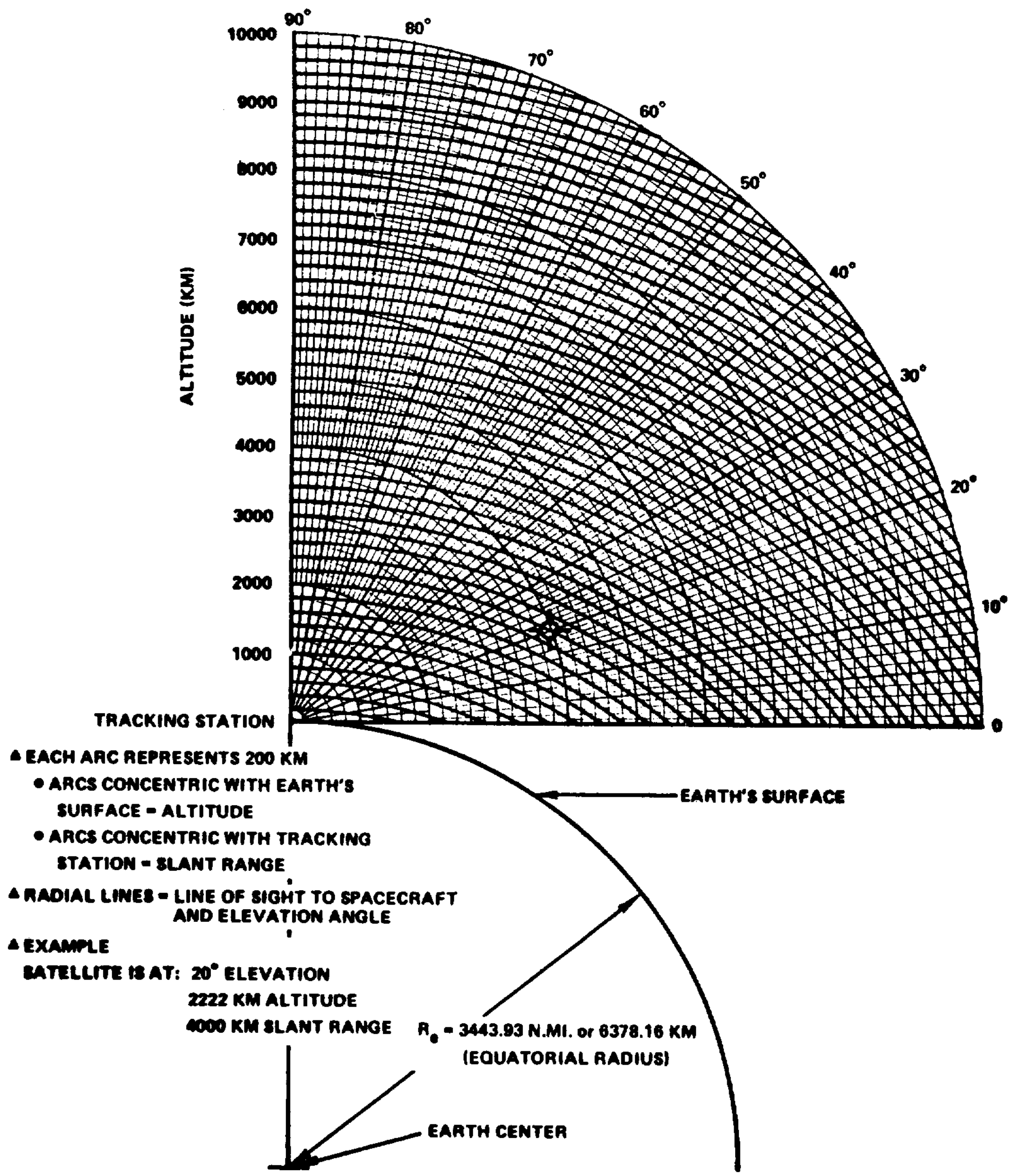


Figure B-3. Slant Range (km) Chart for Altitudes up to 10, 000 km

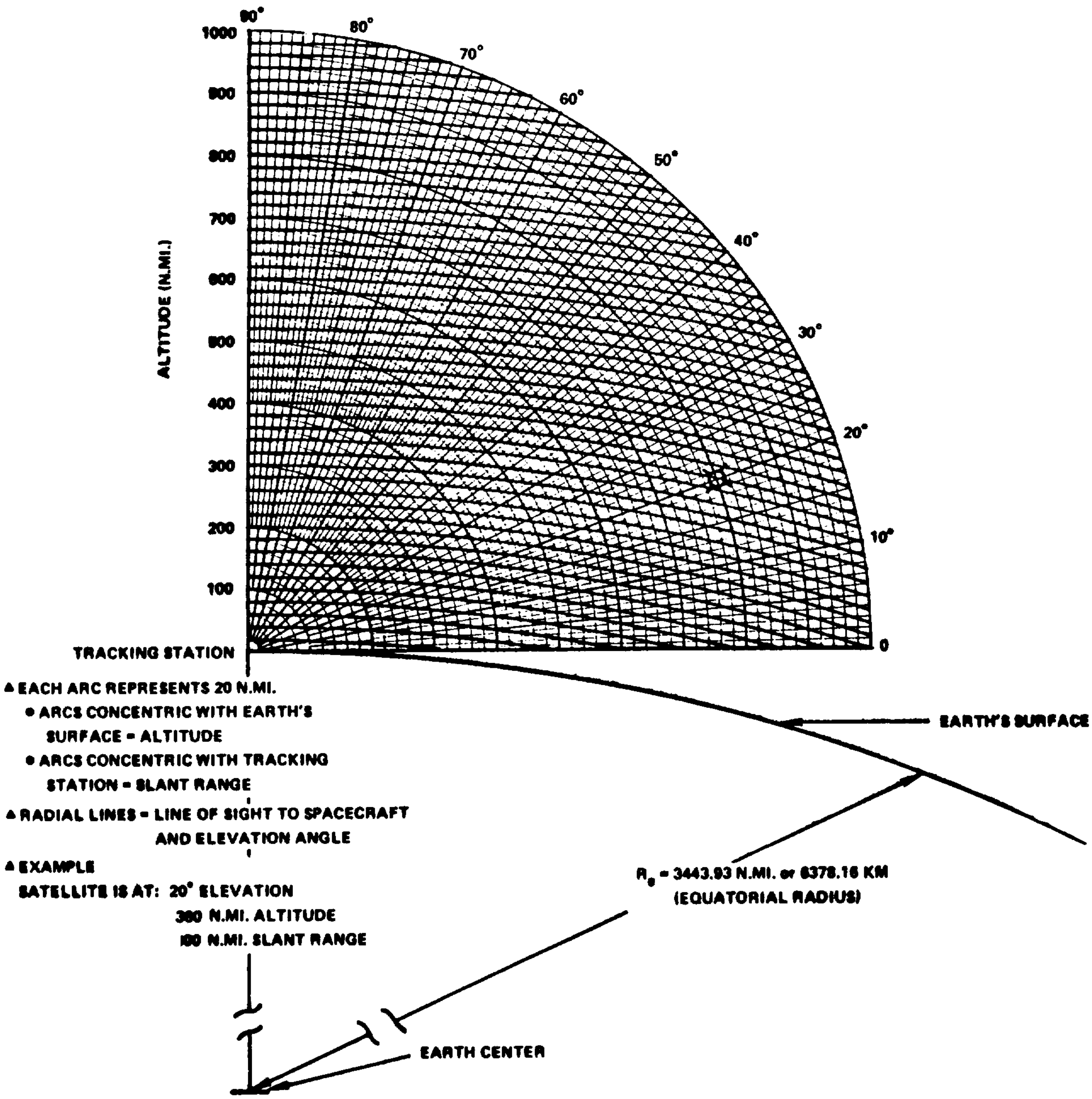


Figure B-4. Slant Range (nmi) Chart for Altitudes up to 1,000 nmi

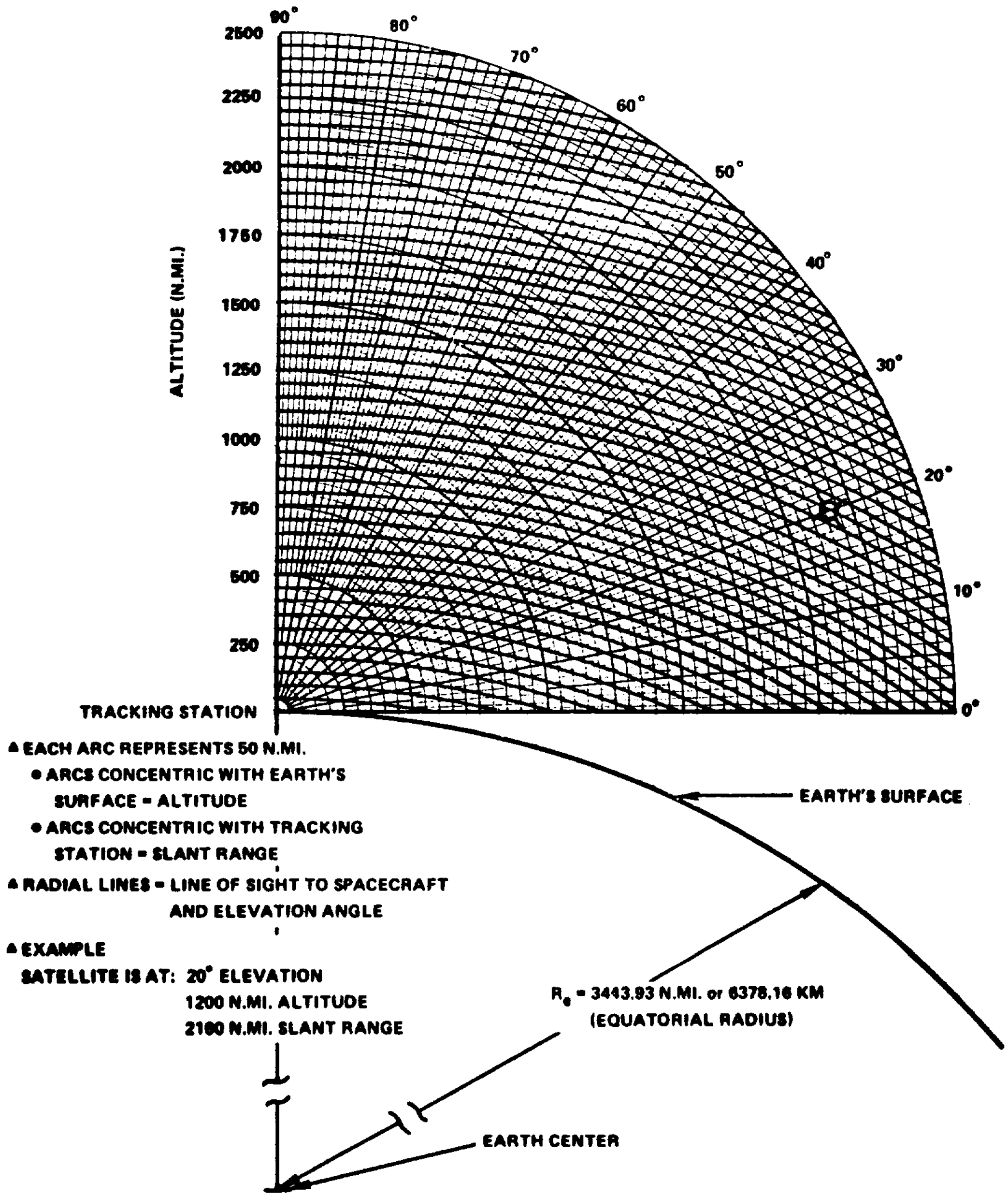


Figure B-5. Slant Range (nmi) Chart for Altitudes up to 2, 500 nmi

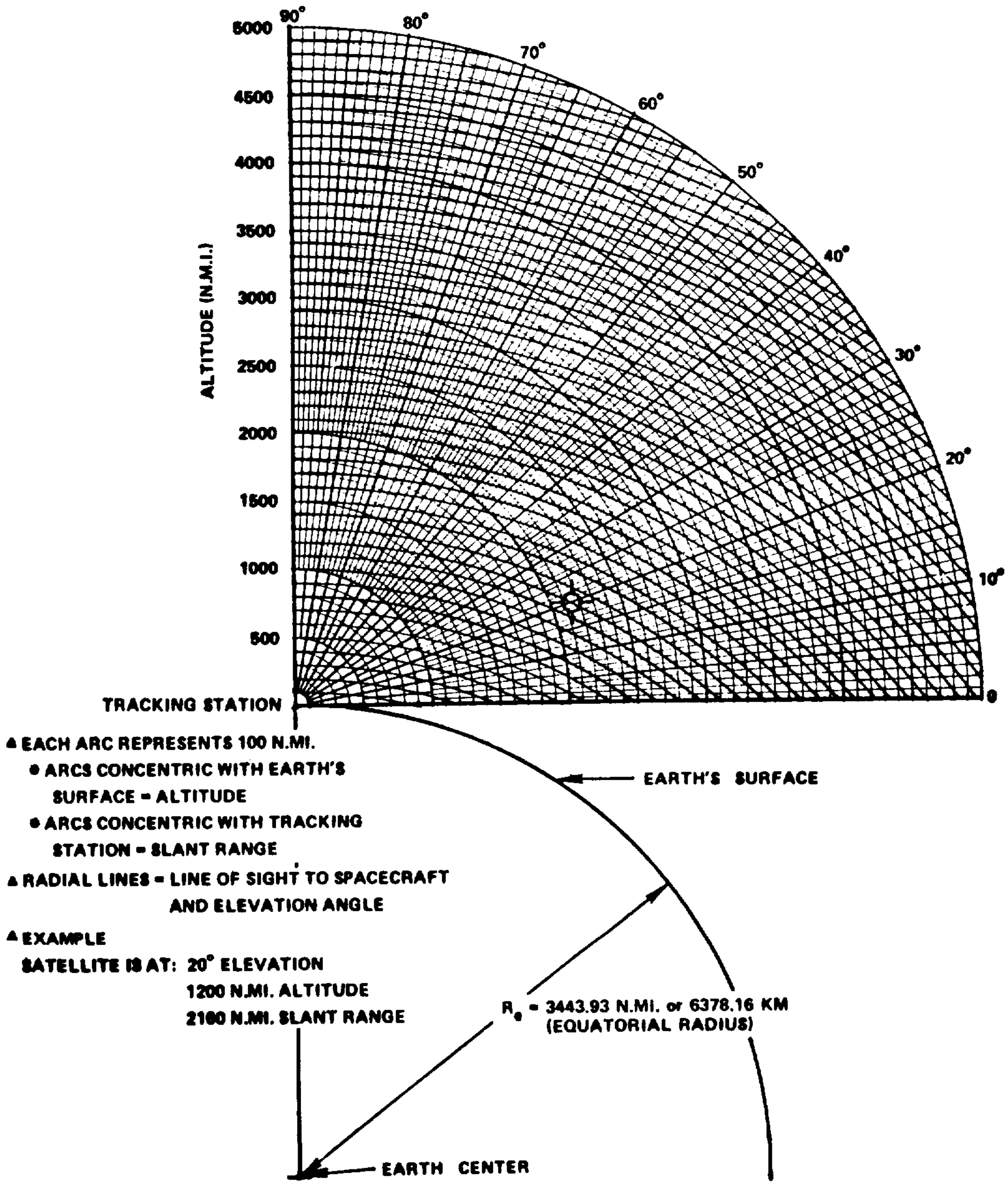


Figure B-6. Slant Range (nmi) Chart for Altitudes up to 5,000 nmi

Glossary

Term	Explanation
ACN	Ascension Island, STDN station
ADRAN	advanced digital ranging system
A-G	air-to-ground
AGAVE	automatic gimballed antenna vectoring equipment
AGIPA	adaptive ground instrumented phased array
AGO	Santiago, Chile, STDN station
ALSEP	Apollo Lunar Surface Experiments Package
AM	amplitude modulation
APP	antenna position programmer
ARIA	Advanced Range Instrumented Aircraft
ASCII	American Standard Code for Information Interchange
ASR	automatic/send/receive
ASTAM	automatic system test and monitor
ASTP	Apollo/Soyuz Test Project
ATS	Applications Technology Satellite
AVE	Mojave ATS support station (California)
BDA	Bermuda, STDN station
BER	bit error rate
BIØ	biphase
BIØ-L	biphase level
BIØ-M	biphase mark
BIØ-S	biphase space
BP	back-up processor
b/sec	bits per second
BUR	Johannesburg, South Africa, STDN station
CAM	computer address matrix
CCIR	International Radio Consultive Committee
CDP	central data processor
CRO	Carnarvon, Australia, STDN station
CRT	cathode ray tube
CSC	Consolidated Systems Corporation
CYI	Grand Canary Island, STDN station
dB	decibel
DDF	digital data formatter
DDPS	digital data processing system
DDR&E	DOD Research and Engineering Office
DIRAM	digital range machine
DOD	Department of Defense
DP	display processor
DSDP	Data Systems Development Plan
DSIF	Deep Space Instrumentation Facility
DSN	Deep Space Network
DTS	data transmission subsystem

Glossary (cont)

Term	Explanation
DTU	data transmission unit
EIRP	effective isotropic radiated power
EMU	expanded memory unit
ERTS	Earth Resources Technology Satellite
ETC	Engineering Test Center, Maryland
FDM	frequency division multiplex
FM	frequency modulation
FP	file processor
FSK	frequency shift key
GDS	Goldstone, California, STDN station
GHz	gigahertz (1000 MHz)
GMT	Greenwich mean time
GRARR	Goddard range and range rate
GSFC	Goddard Space Flight Center
GWM	Guam, STDN station
HAW	Hawaii, STDN station
ICDRAN	integrated circuit digital range tracker
IF	intermediate frequency
INP	internet predict
I/O	input/output
IOCC	integrated operations control console
IRIG	interrange instrumentation group
IRV	interrange vector
ISA	interface system adapter
JPL	Jet Propulsion Laboratory
JSC	Lyndon B. Johnson Space Center
kb/sec	kilobits per second
kHz	kilohertz
Ku-band	10.90 to 17.25 GHz
kW	kilowatt
LCP	left circular polarization
MAD	Madrid, Spain, STDN station
Mb/sec	megabits per second
MFR	multifunction receiver
MHz	megahertz
MIL	Merritt Island, Florida, STDN station
MOTS	Minitrack optical tracking system
MSFC	Marshall Space Flight Center
MSFN	Manned Space Flight Network
MTU	magnetic tape unit
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications Network
NBS	National Bureau of Standards
NFL	Newfoundland, STDN station
NOCC	Network Operations Control Center
NORAD	North American Air Defense Command

Term	Explanation
NOSP	Network Operations Support Plan
NRZ	nonreturn to zero
NRZ-L	nonreturn to zero level
NRZ-M	nonreturn to zero mark
NRZ-S	nonreturn to zero space
NSM	Network support manager
NSP	NASA Support Plan
OGO	Orbiting Geophysical Observatory
ORE	Operations Requirements Extract
ORR	Orroral Valley, Australia, STDN station
OTDA	Office of Tracking and Data Acquisition
PAM	pulse amplitude modulation
paramp	parametric amplifier
PCM	pulse code modulation
PCS	peripheral communications system
PDM	pulse duration modulation
PFM	pulse frequency modulation
PI	Program Introduction
PM	phase modulation
POCC	Project Operation Control Center
preamp	preamplifier
PRD	Program Requirements Document
PRN	pseudorandom noise
PSK	phase shift key
QPSK	quadriphase shift key
QUI	Quito, Ecuador, STDN station
RAM	random access memory
RCP	right circular polarization
RF	radio frequency
ROS	Rosman, North Carolina, STDN station
RSDP	remote site data processor
RZ	return to zero
SATAN	satellite automatic tracking antenna
SATCOM	satellite communications
S-band	1550 to 5200 MHz
SCAMA	switching, conferencing, and monitoring arrangement
SCAMP	satellite command antenna on medium pedestal
SCE	spacecraft command encoder
SDDS	signal data demodulator system
SDTC	serial decimal time code
SFOF	Space Flight Operations Facility
SIRD	Support Instrumentation Requirements Document
S:N	signal-to-noise (ratio)
S:N&I	signal-to-noise plus interference

Glossary (cont)

Term	Explanation
SPADE	Single channel per carrier Pulse code modulation multiple Access Demand Assignment Equipment
STADAC	station data acquisition and control system
STADAN	Space Tracking and Data Acquisition Network
STDN	Spaceflight Tracking and Data Network
TAN	Tananarive, Malagasy Republic, STDN station
T&DA	tracking and data acquisition
TDP	tracking data processor
TDPS	tracking data processor system
TDRS	tracking and data relay satellite
TDRSS	tracking and data relay satellite system
TELTRAC	telemetry tracking (acquisition system)
TEX	Corpus Christi, Texas, STDN station
TLM	telemetry
TP	telemetry processor
TTY	teletypewriter
UDB	updata buffer
UHF	ultra-high frequency
ULA	Fairbanks, Alaska, STDN staion
USB	unified S-band
USNS	U.S. Navy Ship
VAN	USNS Vanguard, STDN station
VCO	voltage-controlled oscillator
VHF	very-high frequency
WECO	Western Electric Company
WNK	Winkfield, United Kingdom, STDN station
X-band	8500 to 10,900 MHz